ULSAN NATIONAL INSTITUTE OF SCIENCE AND TECHNOLOGY

Master's Thesis

Hug2Go: The Development of Indoor Smart Driving Personal Mobility

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A thesis submitted to the Graduate School of Creative Design Engineering, UNIST in partial fulfillment of the requirements for the degree of Professional Master of Design-Engineering

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Advisor

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Executive Summary

This paper presents an initial study on the acceptance of indoor PMVs through providing design and development of a new PMVs (Personal Mobility Vehicles). Hug2Go is the indoor personal mobility, finding passenger through self-driving and going to place by a new way of steering. The personal mobility vehicles (PMVs) emerged as a new category of transportation device in the early 2000s. PMVs offers several potential benefits to consumers and society. Many researchers focused on performance or acceptability of use. However, most of PMVs regarded as outdoor mobility. Recently, popular PMVs has been moved to sharing service area. We thought it opportunity area for the mobility market. In this research, we suppose a new model of indoor mobility and examine it possible to build on the market through the usability test. First, we discovered the context of indoor mobility with existing PMVs driving. Through the observation, we found meaningful insights. Second, we designed and developed indoor PMVs. Third, we conducted a usability evaluation with fifteen participants by using Hug2Go. Experimental results with fifteen participants regarding the acceptance of indoor PMVs validated the proposed latent needs. Finally, we discussed findings and opportunities for improvements. The purpose of this study and the development of PMVs is to provide a comprehensive background for initial research of indoor PMVs.

Keywords: PMVs, The indoor mobility, Self-driving, Autonomous vehicle

Table of Contents

Tables

Figures

1

INTRODUCTION

- 1.1. Background
- 1.2. Research Aim and Method
- 1.3. Thesis structure

1 INTRODUCTION

1.1. Background

The personal mobility vehicles (PMVs) emerged as a new category of transportation device in the early 2000s. PMVs offers many intriguing possibilities for extending the human range of mobility from about 1km to 10km or more. PMVs offers several potential benefits to consumers and society. Many researchers focused on performance or acceptability of use. However, most of PMVs regarded as outdoor mobility. Very few studies address indoor mobility. The indoor space is the daily living environment. People frequently use the airport, shopping mall, transportation. Indoor mobility also can be the area of PMVs.

If shared and autonomous vehicles are adopted as quickly as other technologies (like smartphones, cellphones, and the Internet), significant variance will begin within five years and that the market for individual mobility could modify dramatically over the next 25 years (Figure 1). Recently, Mobility-on-Demand(Mod) services, such as car sharing or on-demand taxi service, have seen massive growth in the last few years through service providers like Uber and Lyft (Andersen,2016).

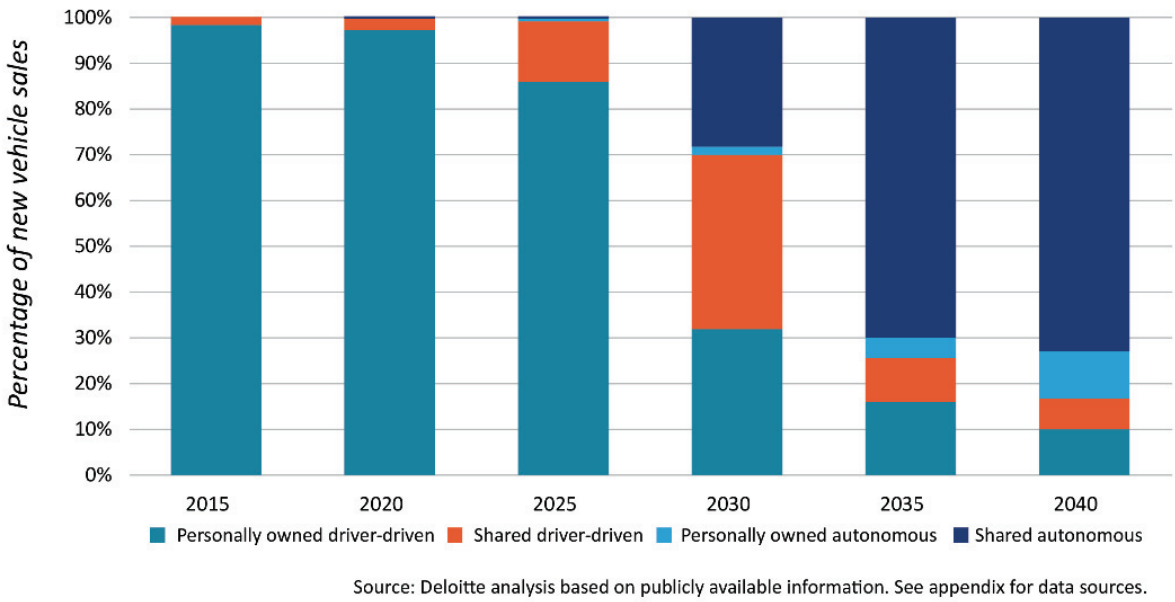


Figure 1. Forecast of new vehicles sales distribution in urban areas in the United States

In addition, many manufactures produce low-cost PMVs for leisure. For example, Segway, e-scooter, e-bike, likewise PMVs become popular for general users. PMVs is more being personalized and owned. PMVs has several potential benefits to consumers, reduced trip times, lower transportation costs. However, the full potential of the category has not been realized, because not yet light enough, do not go far enough, and cost too much for someone.

Recently, popular PMVs has been moved to sharing service area. For example, KICKGOING, GOGO-SSING, deer, SWING, WIND, etc. More than ten company provides on-demand service in Korea. Even though low-cost PMVs is provided for general customers, many people prefer to share than owned. It is growing up.

In the transportation industry, many researcher and specialist reveal future mobility trend as "personal, shared, autonomous" (Scott, 2016). Through the above examples and diagram, we can figure out how it changes. The phenomenon is approaching future trend rapidly than we thought. Therefore, we need to anticipate beyond future trend and present phenomenon that we found. We thought it opportunity area for the mobility market. In this research, we suppose a new model of indoor mobility and examine it possible to build on the market through the usability test.

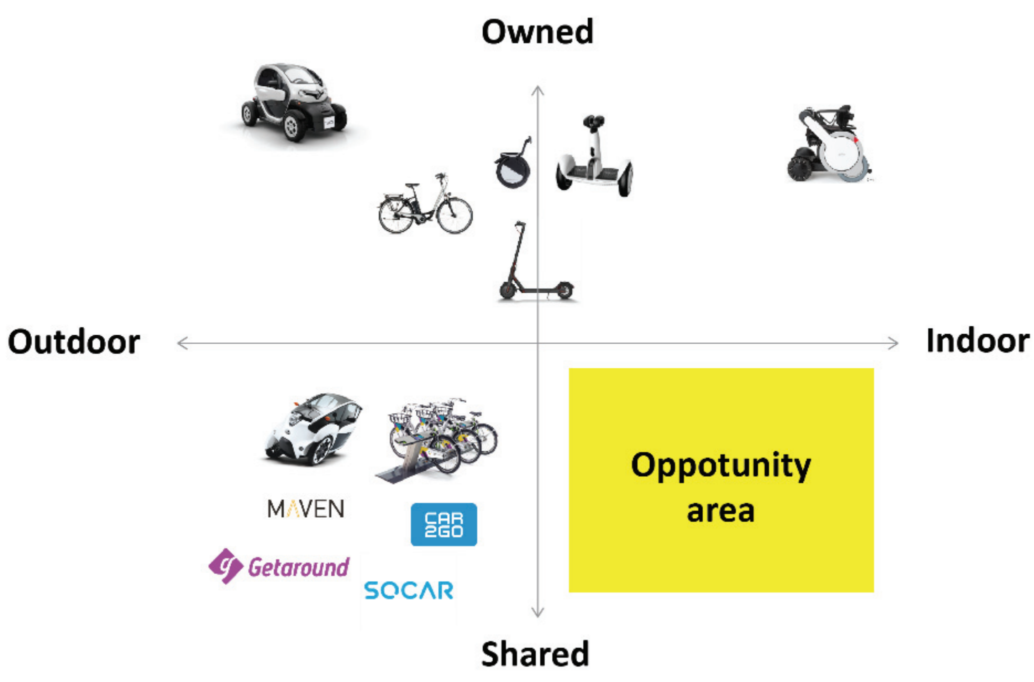


Figure 2. Future personal mobility opportunity area

1.2. Research Aim and Scope

The main purpose is to develop suitable indoor personal mobility concept through design-driven research. The main research question was formulated as follows: What can be done indoor space to facilitate breakthrough outdoor PMVs? Related questions derived from the main question include the following:

- What are the major barrier to inner space to apply existing mobility?
- What is the new design of indoor personal mobility?
- How is the acceptance of indoor PMVs?
- What are the implications for the indoor PMVs?

1.2.1. Research Aim

Through literature review and user observation with PMVs users, we developed an indoor PMVs providing comfortable and safe driving at the inner space. Then, we evaluate the use of steering and driving through a usability test.

First, Discover the opportunity for the indoor mobility

Second, Design and development of a new form of the indoor mobility

Third, Focused experiments and user surveys

Finally, we discussed issues of results related to usability test and were able to understand the limitation and challenge of the Hug2Go design. Eventually, we reveal further works and plans.

1.2.3. Research Scope

In this research, we present the development of indoor PMVs. The main scope of this paper are:

1) *Design and development of a new indoor PMVs capable for manual control:* we suggest a design form of the indoor personal mobility.

2) *Embedded system has implemented: we consider building cost-effectiveness commercial product on the market. In order to lower cost, we develop a system by ourselves.*

3) *Usability test and user survey*: we examine the intended the hug steering uses of the Hug2Go

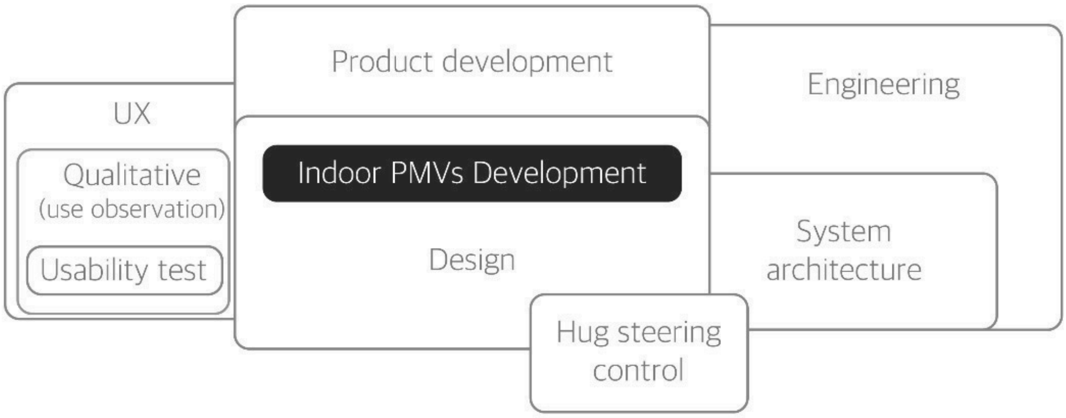


Figure 3. Research scope

1.3. Thesis Structure

This paper is organized as follows.

In Chapter two, a brief overview of the previous studies related to PMVs will be reviewed.

In Chapter three, we describe the Hug2Go design and propose a method of manual control for the Hug2Go using the hug steering.

In Chapter four, we address the procedure of a usability test. The results will be presented through an analysis of both qualitative and quantitative data.

In Chapter five, the intended uses of the Hug2Go are examined using the empirical results will be discussed.

In Chapter six, we present the outcomes and contributions of the research and suggest further works and directions.

2

PRELIMINARY STUDY

- 2.1 Related works
- 2.2 Observation to insights

2 PRELIMINARY STUDY

2.1. Related Works

The personal electric vehicle(PEV) emerged as a new category of transportation device in the late 1990s. Some studies have been conducted to analyze and discuss PMV use, especially for self-balancing personal transporters, such as Segway. (Ulrich, 2005) pointed out that PMVs offer several potential benefits for users and society, including lower transportation costs, reduced trip times, and low environmental impact.

(Sawatzky, 2007) studied the use of the Segway as an alternative mobility device for people with disabilities and concluded that subjects with disabilities through the Segway was easy to use, and we are excited about its potential to assist them. (Miller, 2008) analyzed the approach speed and passing clearance that Segway devices exhibit on encountering a variety of obstacles on the sidewalk.

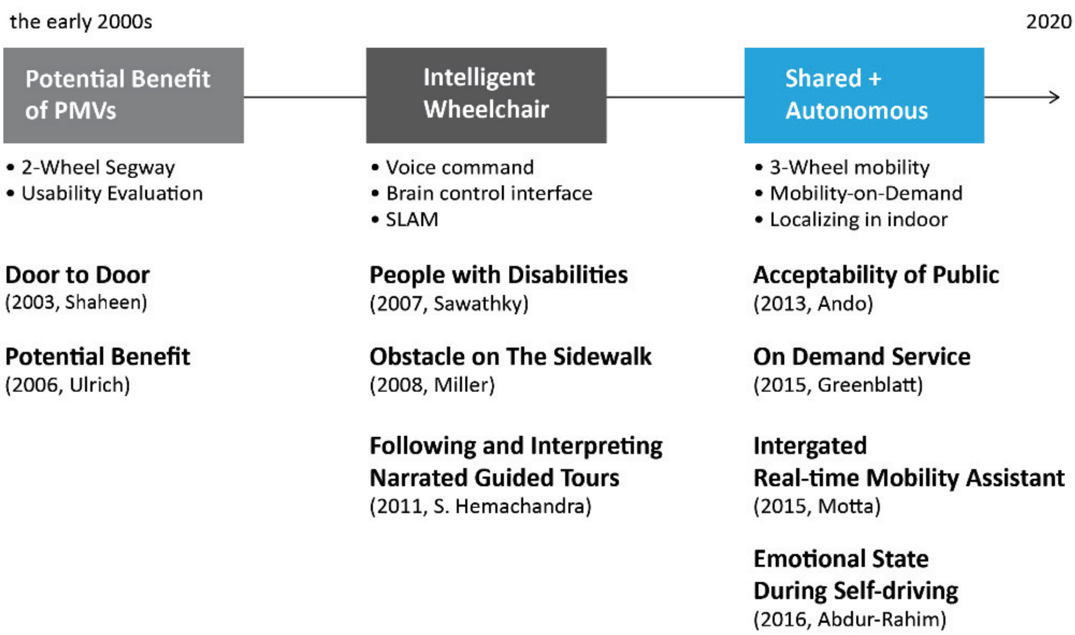


Figure 4. Previous study trend in PMVs industry

Recently, transportation and robot researchers have been increasingly interested in autonomous and shared vehicles related to PMVs. (Ando, 2013) suggests that a critical factor in successfully introducing PMVs for use in the future is understanding social acceptance. (Fujikawa, 2012) propose for an IR system to support automatic control for PMVs (Figure 5, Fujikawa 2012). They designed four-wheeled mobile bodies that are widely used in practical locomotive machinery. It is not only for outdoors but also for indoor mobility environments such as station or open public area. With multi-sensor based or self-driving module, some research includes perception of users and identifying open concept to the autonomous personal mobility device (Abdur-Rahim, 2016).

Nevertheless, the form or design of indoor mobility seems to be lacking. The overall research-driven system is described in Figure 5. Typicality and novelty have often been shown to be related to the aesthetic preference of human artifacts (Hekkert, 2003). The core of all question is the most advanced yet acceptable system in the design perspectives.

In the next chapter, we discover the problem when the outdoor types of PMVs come into indoor space through observation. In addition, we also find insights from observation.

Fujikawa (2012) J.Abdur-Rahim (2016) H.Andersen (2016)

Figure 5. Autonomous and shared

2.2. Observation to insights

The purpose of observation is to discover the context of indoor mobility with existing PMVs driving. In order to gather observation, we conducted driving experiment with 11 people aged from 20 to 50 years old (3 females, 8 males). We use three different types of PMVs such as Segway, E-scooter (stand-on) and E-scooter (sit-on) (Table 1).

Table 1. Commercial product specification

Category	Segway	E-scooter (stand-on)	E-scooter (sit-on)
			
Product	XIAOMI	Nano Pro, SPEEDWAY	ECORO s50
Dimension	260 x 552 x 630	980 x 380 x 1040	450 x 890 x 1090
Top speed	18km/h	28km/h	25km/h
Empty weight	13.4kg	8,1kg	25.2kg
Maximum payload	100kg	100kg	150kg
Range	30km	20km	35km
Power	63V/310Wh, 400W	36V/6.4Ah, 250W	36V/10.4Ah, 540W
Charge time	3.5hr	4hr	4.5hr

2.2.1. Experimental Task

Figure 6. displays a timeline view of the experiment. Participants required online google survey. Following, participants were informed about task. First, the experimenter gave each participant an explanation of the driving course and how to manipulate PMVs. After each of the three vehicle driving trials, questionnaires were administered to determine the participant's experience feelings (Appendix A). Finally, we interviewed each participant after finished.

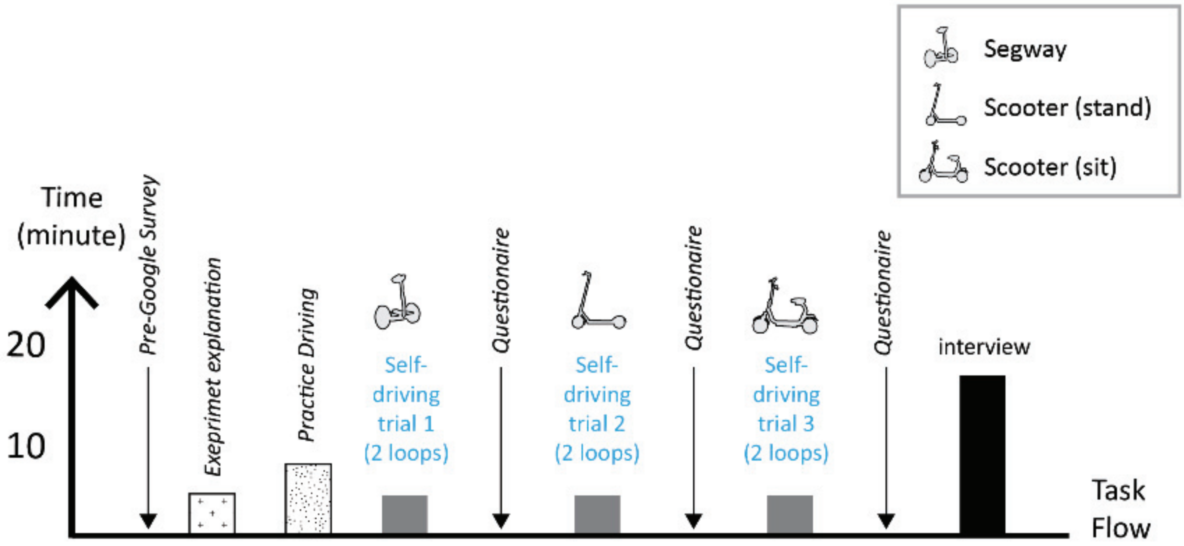


Figure 6. Experimental task procedure

2.2.2. Pathway

Figure 7. describes experimental driving task pathway. Participants drove PMVs manually for loop course starting point to end. The participant is intended to avoid obstacles such as pillars.

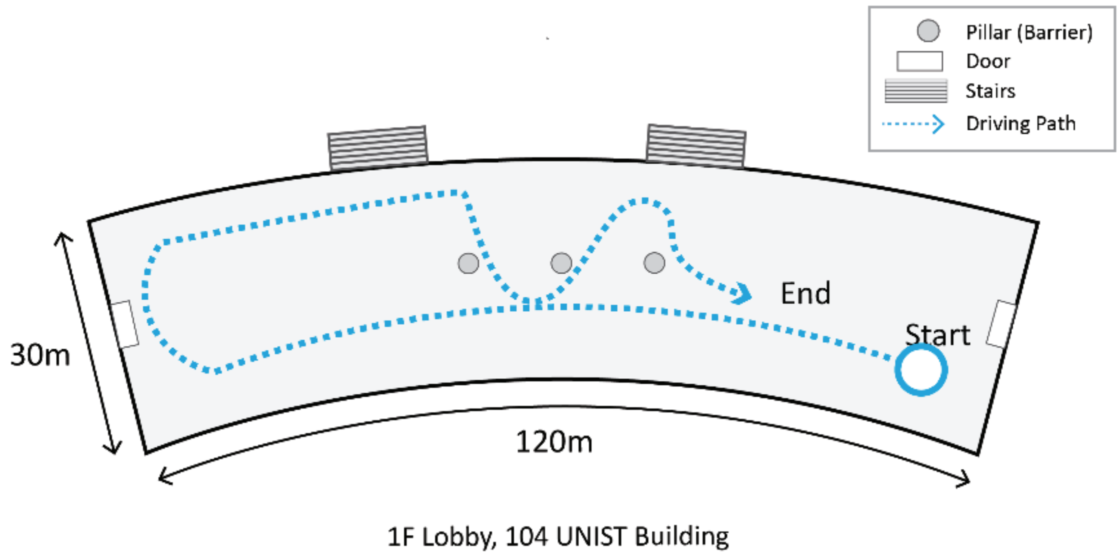


Figure 7. Top view of driving task pathway

Table 2. insights from observation

Observation	**Insights**	**Function**
As soon as using the acceleration button, She is afraid of the rapid acceleration.	The acceleration of speed has been limited at the starting point.	Safety
Many of them didn't find the power button	Users can notice the position of power supplier.	Convenience
Emergency situation	Users should control the emergency situation without difficulty	Convenience
He boarded the Segway without turning on power	Users are able to recognize controller without difficulty	Convenience, Safety
He feel fear to get out of the Segway	The indoor mobility keep users safe from unexpected situation on getting out the mobility.	Safety
I want to know how fast speed is	Users want to be aware of the speed in the driving.	Safety, Convenience
e-Scooter (sitting) is lower than standing type	PMVs must keep providing user's sight.	Safety, Convenience
A participant wave to say hello someone on driving unconsciously	PMVs must prevent the accident from unexpected situation	Safety
He put his feet on the ground on driving	Users want to control the mobility completely	Safety
She just try to push unknown button to start it	The consequence of control should be expected	Safety
A heart sound is getting more faster on video because he is nervous	Users should be aware of convenience and trust during the driving	Safety
The space is limited when participants are turning on the pillar	Indoor PMVs should consider the limited space.	Safety
It is not for elderly or kids	Self-balancing PMVs is not universal for everyone	Convenience
Pedestrians is latent risk	Indoor PMVs must consider the pedestrians in the path	Safety
The long form of mobility has risk on turning	Users are aware of the inconvenience and risk on turning	Safety
Even though they use it in indoor, they thought that it is just outdoor mobility	The indoor mobility should have an optimal form	Appearance
Sitting is safe	PMVs should be comfortable on driving	Safety
Segway enable us to be hands-free	User want to hands free	Convenience
If we meet the shared mobility, we have to spend time to be used to mobility	The indoor mobility should provide trust to users in sequence of driving (boarding, getting out, driving)	Convenience
The space is limited in door (elevator, corridors, etc.)	The indoor mobility should have an optimal size	Appearance

2.2.3. Insights and findings

In short, we obtained twenty-three of insights from observation (Table 2). Then, twenty-three of insights can be connected with functional requirements. Thirteen of insights are related to safety; eight of insights are the convenience; others are appearances.

We conducted a pre-google survey for gathering quantitative data. The experimental results (Figure 8) show that the value of acceptance, such as safe, fun, intuitive, universally accessible, efficient, fun is entirely positive. However, there is an exception to the result. Segway is not enough.

It follows from what has been said that we should consider insights from commercial PMVs and we figured out the possibilities of the indoor mobility.

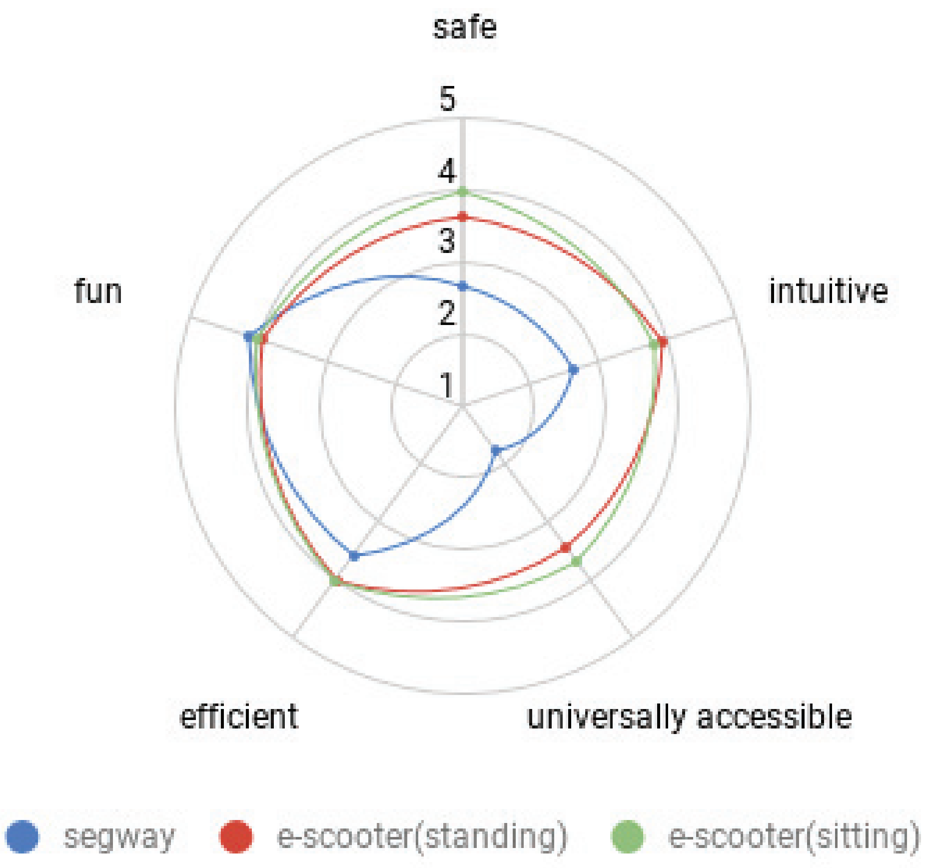


Figure 8. Acceptance of commercial PMVs to the indoor

3

Hug2Go
The Indoor Smart Driving Personal Mobility

3 Hug2Go

3.1. Defining target area

We define the target space as it is the large indoor spaces segment. It includes building which has a huge indoor area such as malls, station, museums, convention center and airport (Figure 9). A convention center will be the target space. It is a modern convention center in which one or more buildings from a complex of shops with interconnecting walkways. Others such as station, museums, convention center and airport also have huge indoor space with pathways. Probably, people are walking along passage connecting different sections of a building in these malls. It frequently happens in the huge indoor environment.

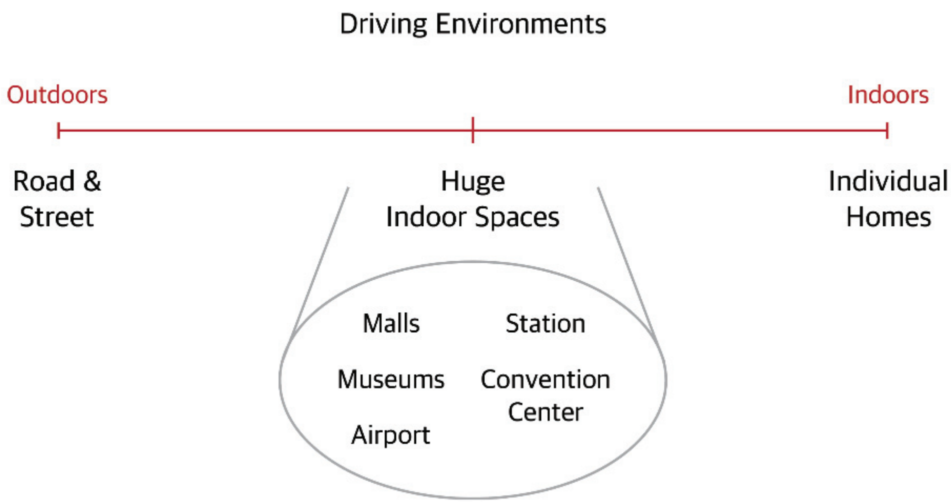


Figure 9. PMVs Driving Environments

Specifically, the area of huge indoor spaces is more than 20,000m^2 at least. There are representative convention center in Korea (Table 3).

Table 3. Area of convention center in Korea

	EXCO	COEX	BEXCO	KINTEX
Location	Daegu	Seoul	Busan	Goyang
Area (m^2)	26,508	36,736	54,731	108,483

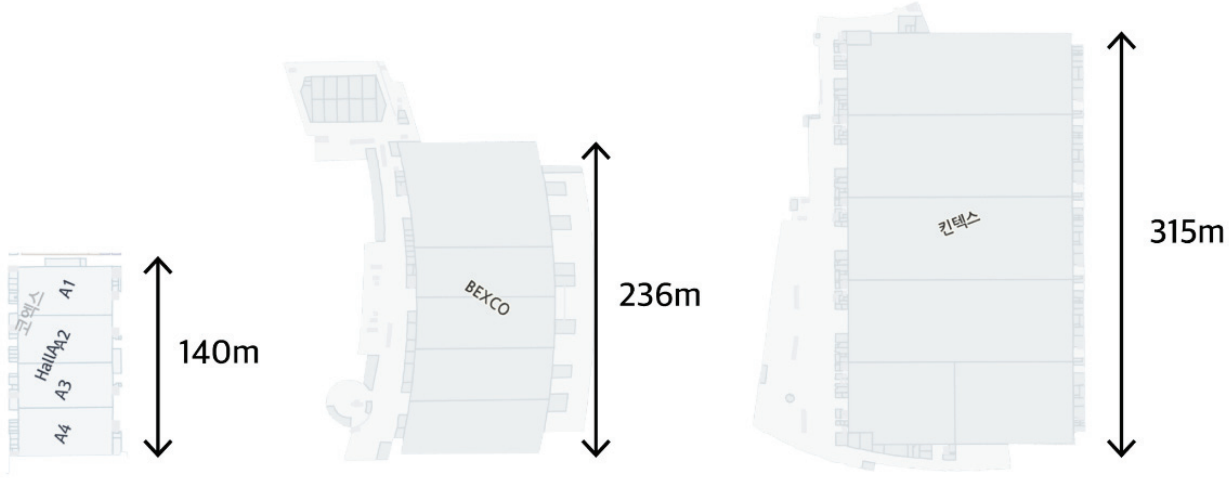


Figure 10. The area of convention center

Figure 10. show the area of convention center. The walking makes people exhaust in a large space. Even though they want to spend going somewhere, it's physically exhausting. It's a long journey in large space.

We can assume the traveling in convention center. Figure 11 describes comparison between the average daily walking and traveling in convention center. Approximately, Traveling is ten times than the average of daily walking distance. It's obviously long journey for walking. Therefore, it is certain latent needs and we are targeting on a large space.

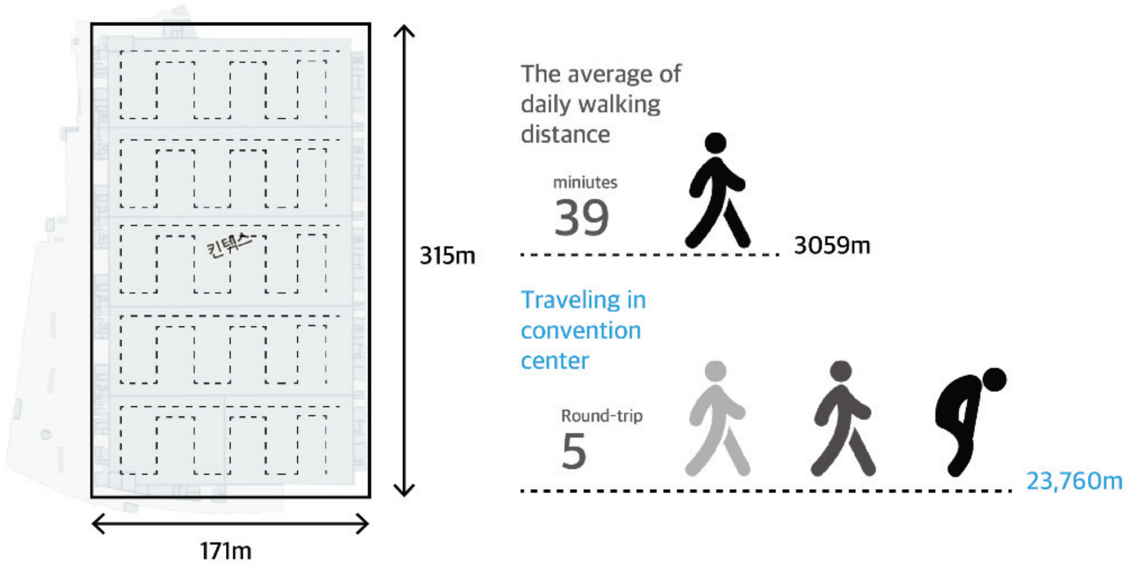


Figure 11. Frustrated walking in huge space

3.2. Design features

Hug2Go is the indoor personal mobility, finding passenger through self-driving and going to place by a new way of steering. The mobility is intended to work corporately with people to improve the efficiency of time or energy indoor environment. Primarily, Hug2Go provides three types of operating mode. It usually requires self-driving for finding the passenger. Sometimes, it could be a comfortable chair. If a user wants to control the mobility, they are also able to operate the steering. Therefore, the switching is essential part among mode use. In order to discern between chair mode and control mode, we use sensors to detect a passenger's position. Finally, we suggest "hug steering" as a new way of steering. we called it hug steering because a user needs to hug seat back to control the mobility. It might be a quite new steering system.

Figure 12. Finding passenger through self-driving inside an airport

3.2.1. Three types of operating mode

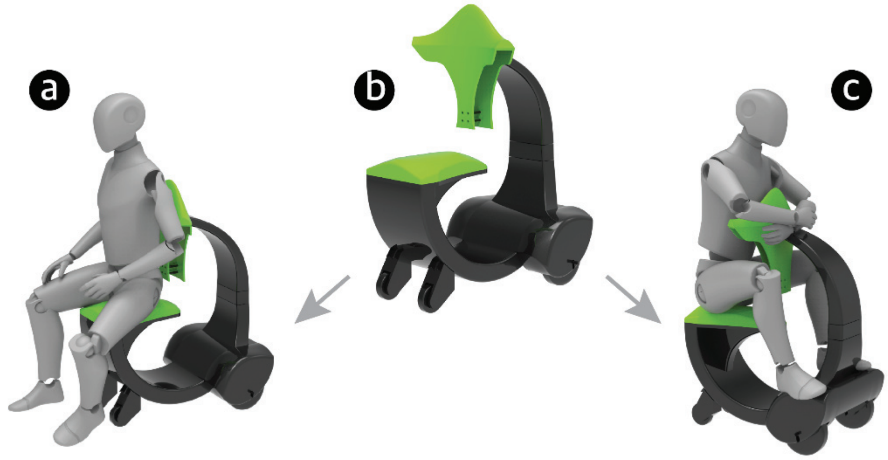


Figure 13. (a) Chair mode, (b) Self-driving mode, (c) Control mode

Hug2Go provides three types of operating mode (Figure 13, a, b, c). The modes can be changed by each other. First, chair mode supports temporary breaks for users. The passenger can sit and take a break comfortably when the mobility is stopped. Second, a self-driving mode is finding the passenger who wants to ride on the mobility. Hug2Go maintains a safe distance with people through multiple sensors while the self-driving mode is moving. When users send gestures or voices for boarding signs to mobility, Hug2Go will reach over the passenger. Third, the control mode means manual operating. If the passenger wants to control the mobility, they can use facing seat back as steering. Users should sit on a seat back in the opposite direction. Facing back becomes steering. They can control the direction through the rotation, push, and pull.

As above mentioned, Hug2go enable a passenger to select different modes. 4 ToF (Time of Flight) sensors are installed to detect passenger's position. The overall location of sensors is described in Figure 14. The sensors are mounted on seat and front cover where they detect passenger's leg or part of the body.

3.2.2. Switching modes

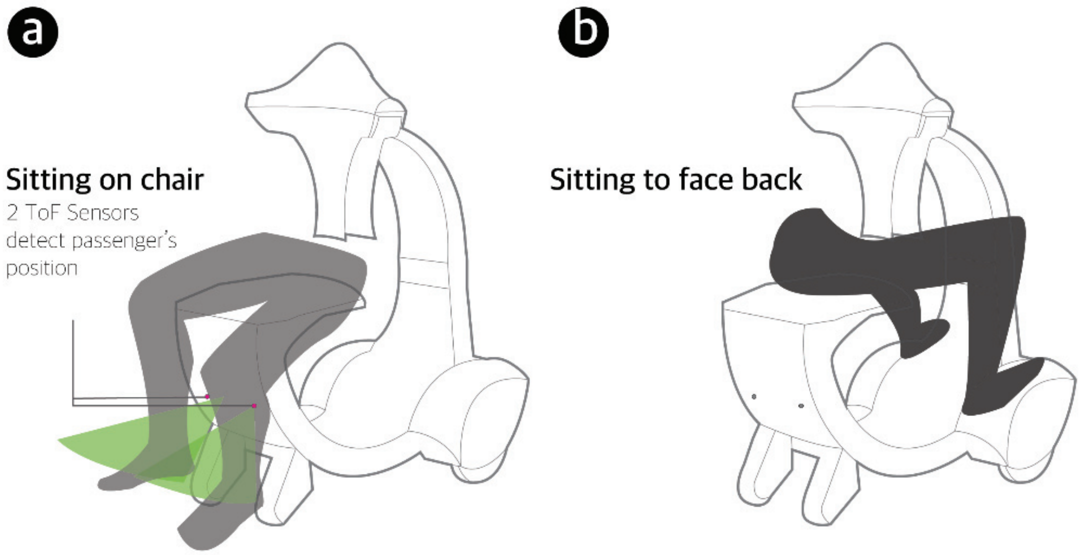


Figure 14. Detection of position (a) Chair mode, (b) Control mode

3.2.3. Sitting on chair (chair mode)

On self-driving, the mobility reaches to passenger and stops in front of the user. Unless the user wants to control the mobility, the user can sit on leaning back. Then, 2 ToF sensors detect a user's part of the body under the knee. If ToF sensors detect user's body, Hug2Go is not controlled by any forces. (Figure 14, a)

3.2.4. Sitting on a chair facing in the opposite direction (control mode)

In order to control the mobility, a user must sit on a chair facing on the opposite side. Then, 2 ToF sensors which is mounted on front cover detect passenger's leg or part of the body. If ToF sensors detect the user's part of the body, Hug2Go's control mode is only activated. After that, the user can control the mobility through using hug steering.(Figure 14,b)

3.2.5. The hug steering

Steering of mobility is an essential activity. However, the most traditional steering is still insufficient. Especially, there is no optimal standard related to indoor personal mobility. We needed a new way of steering suitable for indoor mobility. In this paper, we follow the form of the chair. Therefore, we consider relevant steering for Hug2Go as soon as possible. The most basic ideas of criterion are from sitting on a chair facing in the opposite direction. Everyone might have an experience such an opposite posture in the chair. This is not stable but pleasant. We believe that such an experience makes it funnier steering experience. Finally, we can suppose “hug steering” (Figure 15).

The hug steering is steering implemented in Hug2Go. It is a new way of steering, which means that it contains a hug motion. “Hug” is squeezing someone tightly in one’s arms, or holding something carefully or tightly round or against part of one’s body.

Figure 15. Passenger’s hug steering posture

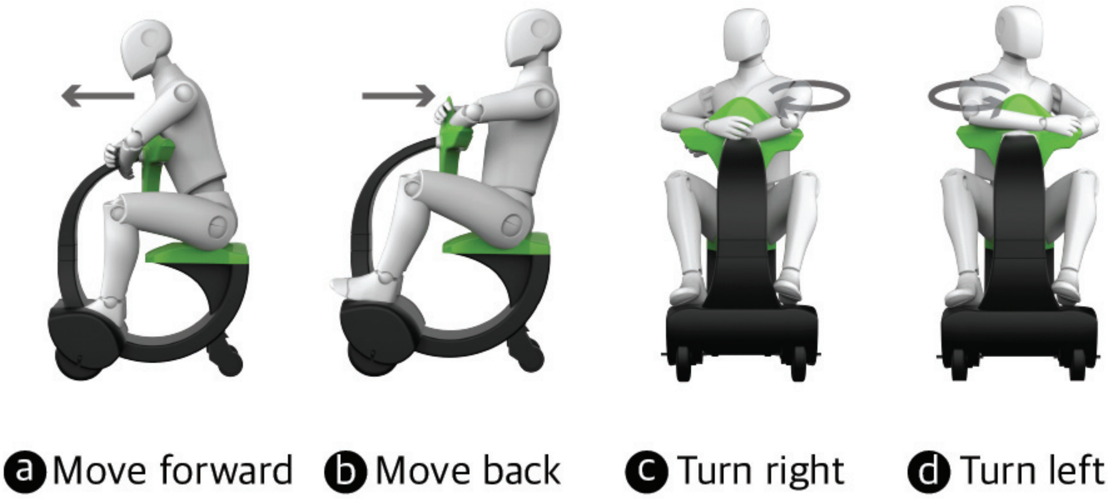


Figure 16. The hug steering motion

The hug steering produces four types of steering motion (Figure 16). User can push, pull, and rotate hug steering. If the user push the seat back, the mobility is moving forward (Figure 16, a, b). To pull the steering means moving back. In order to turn in a circle, the user rotates the seat back to left or right without pull and push. Then, the mobility is rotating toward rotating direction (Figure 16, c, d). The user probably needs an operating rotation of mobility on moving forward or back. It is a different operation with turning in a circle when it stops. If the user pulls or pushes and rotates the steering simultaneously, the mobility moves the direction to which the user rotates on driving. The strength of the rotating makes how it moves quickly.

Table 4. Use & Operation of hug steering

Types	Use	Operation	Direction
(a)	Push	Move forward	↑
(b)	Pull	Move back	↓
(c)	Rotate (right)	Turn right	↻
(d)	Rotate (left)	Turn left	↺

3.3. Implementation

In this research, we focused on manual mode. Hug2Go two kinds of operation (Figure 17). The self-driving is an essential part of our development. The development of autonomous personal mobility devices has been an active research area recently. Many researchers are developing autonomous mobility. However, It still costs huge money. One of the focus in this research is to provide a lower cost platform than previous research platform. Therefore, we examine the possibility of low cost and plan to develop self-driving mobility step by step. It will develop in the next research.

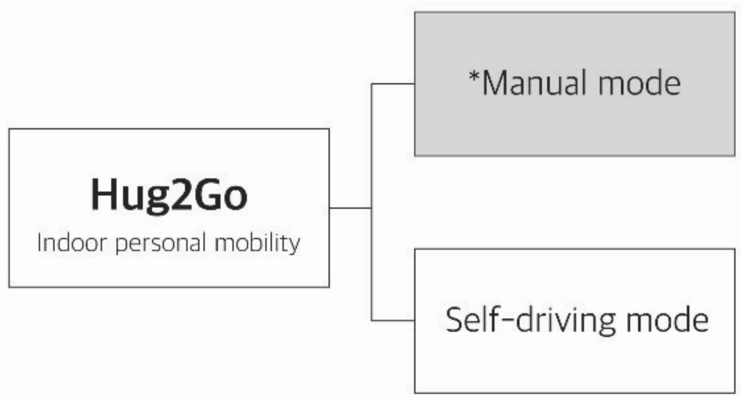


Figure 17. The main structure of operation

First, we begin to prepare functional requirements (Table 5) in order to develop manual mode. The typical architecture of a personal electric vehicle is comprised of the essential functions of energy storage, drive system, and chassis. We discuss the driving system and chassis without self-driving in this research.

Table 5. Functional requirements.

Mode	Function	Component	Part
Manual	Moving, rotating	Motor	BLDC motor
	Control	Steering	Load cell
	Sitting / mode change	Seat	Seat
Self-driving	Mapping & localization	Sensor	ToF sensor
	Self-charging	Charging	Battery, auto-charging system
	Obstacle detection	Sensor	ToF sensor

3.3.1. Hardware

Table 6. Hug2Go Specification

Dimension (L × W × H)	80cm x 60cm x 120cm
Empty Weight	25kg
Maximum payload	100kg
Maximum speed	8.0 km/h
Range	4.5h
Power	36V, 10Ah

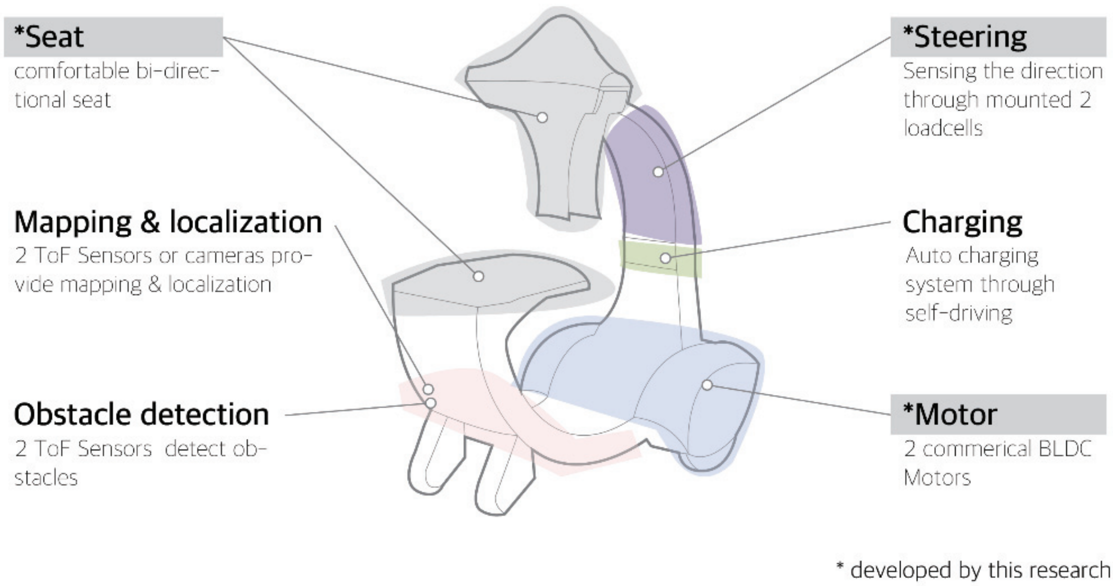


Figure 18. Hardware overview. highlighting means development of level 1 of (manual mode). Not highlighting means development of level 2 (self-driving mode).

The overall design describes a round plane figure whose boundary consists of points equidistant from a fixed point. The platform consists of six parts (Figure 18). In this research, we focused on manual mode. Therefore, we developed a seat, steering, and motors. A metal structure customizes the base platform. It is the main body which connects with a seat back, seat, wheel, and canisters (Figure 19). t draws the shape of the ellipse. Both edges place to seat and seat back. The motor is mounted to under metal structure. Steering actuation is achieved using two load cells. We will deal with details below.

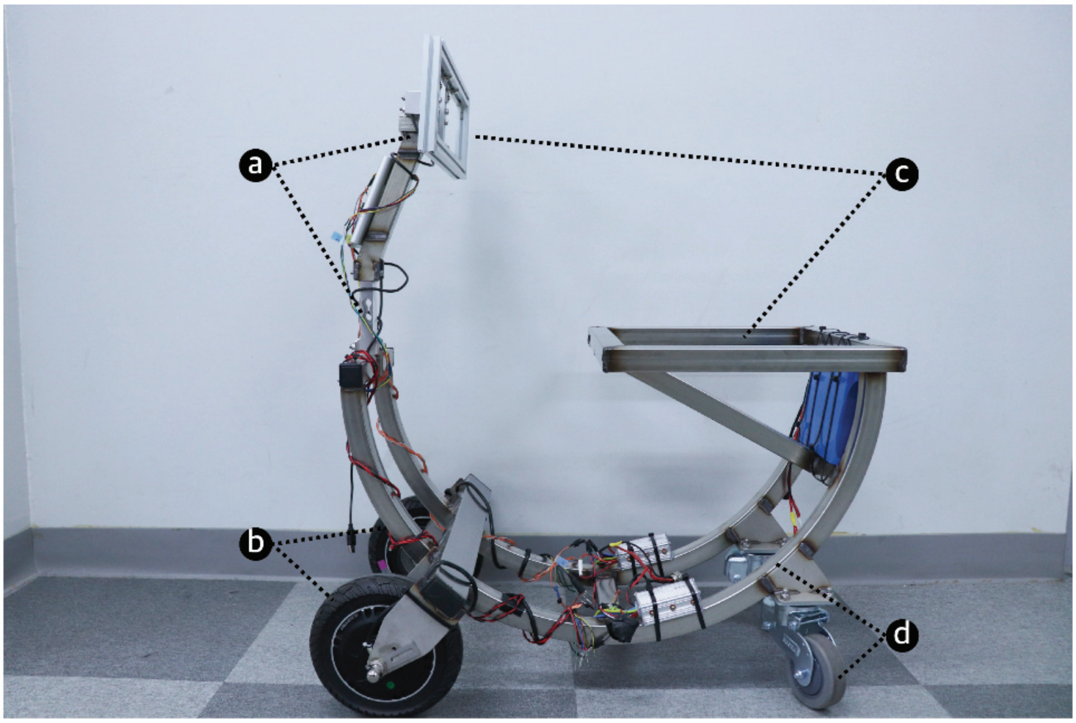


Figure 19. The base platform, (a) Load cell, (b) BLDC motor, (c) Seat, (d) castors

3.3.2. Motor

Two BLDC motors are installed to move the mobility's driving wheel. The mobility comes with 36V, 10Ah internal lithium-polymer battery, used to power the main motor as well as the accompanying primary circuit. BLDC motors offer advantages over brushed DC motors, including higher reliability, longer lifetime (no brush erosion), elimination of ionizing sparks from the commuter, and the overall reduction of electromagnetic interference. Brushless motors are considered more efficient than brushed DC motors. This means for the same input power. A brushless motor will convert more electrical power into mechanical power than a brushed motor.

Figure 20. BLDC motor (48V, 350W), Battery (36V, 10Ah)

3.3.3. Steering

Manual controls of the mobility can only be achieved through output signals with two load cell installed. Additionally, stop-button is also used to stop it when the vehicle is out of order from the intended path. It prevents a potential safety hazard.

The longitudinal speed control of the vehicles is achieved by an analog voltage input to the motor driver to imitate the output from independent two load cells linked to the main body. There is two control input to the mobility: steering and speed. The speed input value to the steering can also take negative value indicating reverse motion. The central controller channel takes an input signal of 0-3.3V, with 0V being zero speed, and 3.3V being maximum forward speed. The maximum velocity of the mobility is set limited to 5km/h.

In order to operate manual driving, the vehicle needs two beam types of the load cell. A load cell is 130mm × 30mm × 22mm (L × W × H). The rated max output is 2mV/V. It is the output voltage when the rated capacity of 50kg is loaded. A load cell consists of a metal element that is introduced to a change through tension (pulling apart) or compression (pushing together) forces and interior strain gages that sense this change. Then, the hug steering needs four types of motion. Therefore, the load cell provides independent four signals. Normally, a load cell makes two signals at least through tension and compression. We used two load cell to make four signals from the independent position of the load cell.

Proper position of the load cell is described in Figure 22. Two load cell is mounted to the frame covered with a seat back. It means that mounted two load cell is connected indirectly. Therefore, we need to determine the relevant position through the test. Finally, we selected the position (Figure 22, c, d) because of the independent relationship between each load cell.

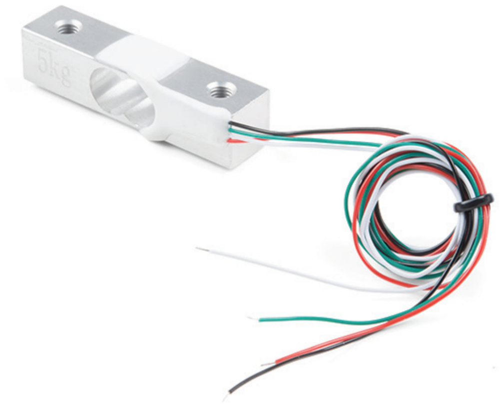


Figure 21. Load Cell 4 wire (50kg, 2mv /V)

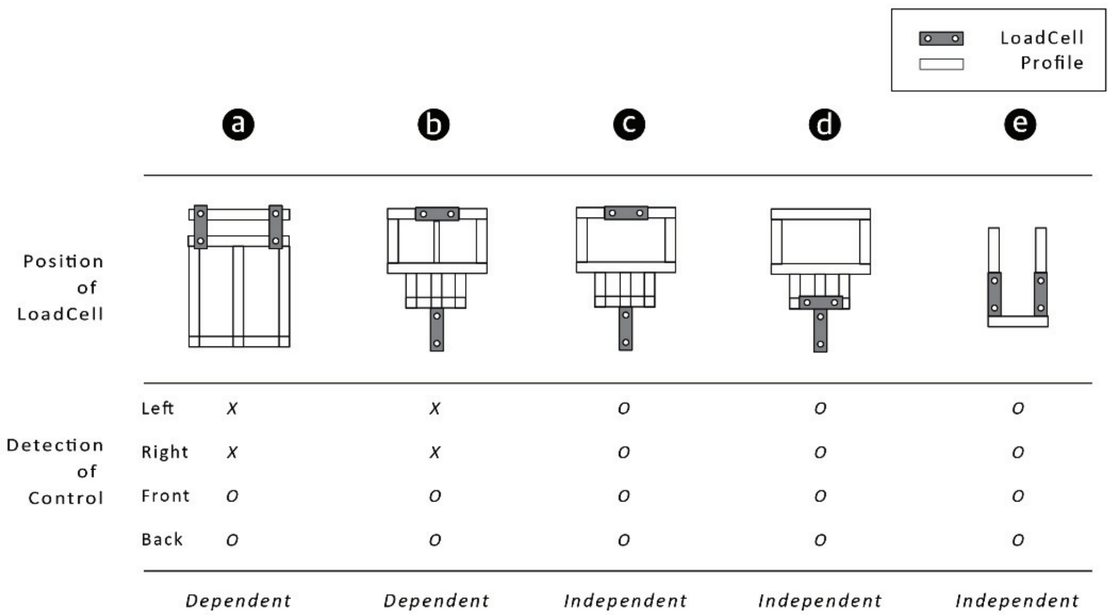


Figure 22. Relevant position of load cell

3.3.4. *Seat and seat back*

The seat and seat back enable users to rest comfortably. We regarded seat as a critical factor of safety. We considered using a soft foam pad. In order to assemble a cushion and back frame, we need to put the cover on the foam pad and assemble the rear frame to assemble a basic seat shape. In this research, we only want to focus on frame parts because we did not decide the shape of foam and choose material yet.

Figure 23 describes the process of making a seat frame. We selected carbon fiber as materials. Carbon fibers have several advantages, including high stiffness, high tensile strength, low weight, high chemical resistance, high-temperature tolerance, and low thermal expansion. First, we prepared a mold for combining polyester resins (Figure 23, a). CNC machines make it excellent shape from 3d modeling. Typically, polyester resins reinforce mold more harden (Figure 23, b). After filled with resin, we can bond together with fabric. The fabric is composed of woven carbon filaments (Figure 23, c) The bonded surfaces between resin and fabric take about 12 hours. Finally, we apply at least three more layers of resin. These layers of resin are intended to improve the look of the part, not the strength or functionality. After that, we sand the top layer of resin and polish the part (Figure 23, d).

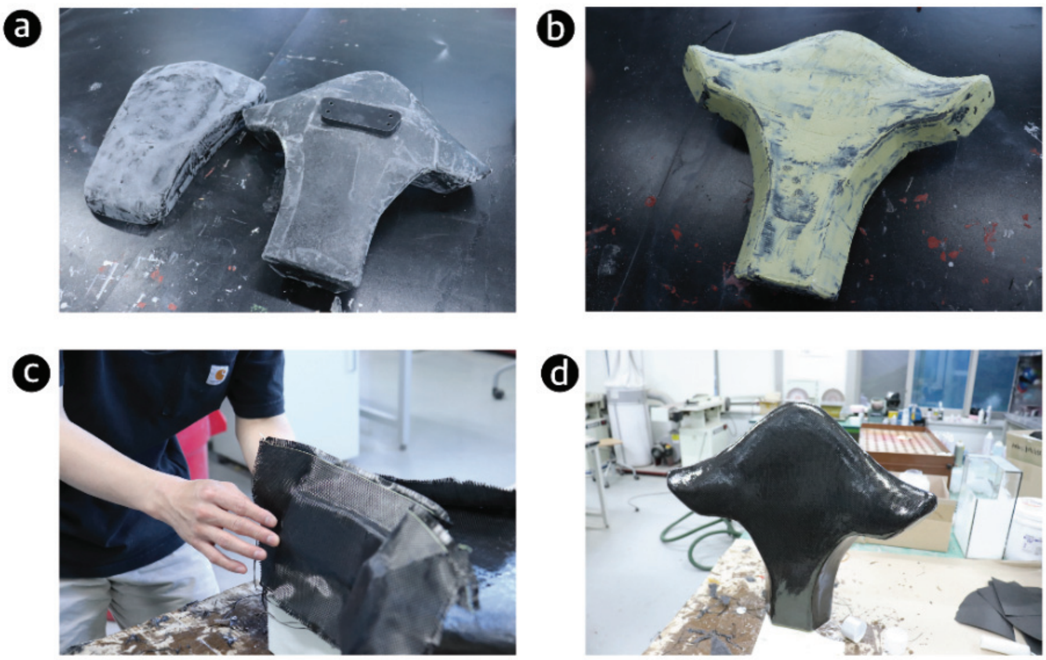


Figure 23. The process of making seat frame, (a) prepare mold, (b) spray resin, (c) laying carbon fiber, (d) finishing parts

3.3.5. Embedded system

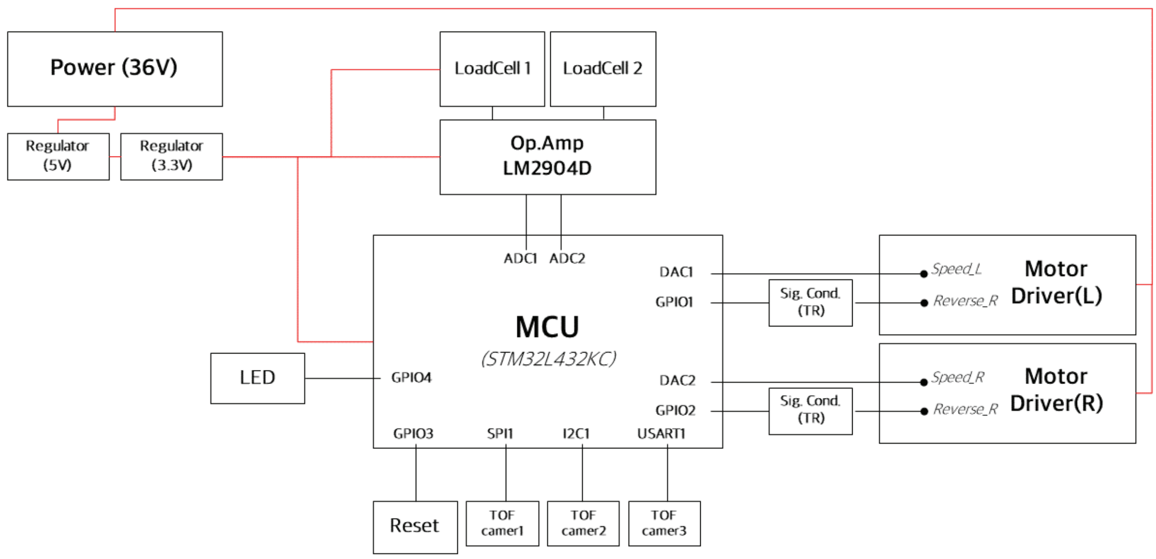


Figure 24. Block Diagram

An STM32L432KC microcontroller is used to publish a control signal to the BLDC motor, to read the load cells and communicate with the hug steering. we use Arm MBED OS, which is an open-source embedded operating system. It includes all the features to develop connected product base on Arm Cortex-M4 at 72MHz microcontroller, including security, connectivity, and RTOS. A custom-designed circuit board is mounted to mobility inside.

The passenger of mobility has access to the board on mobility. The ToF sensors detect the signal whether the passenger has arrived. In order to detect the passenger’s motion, it needs two at least. There are two available modes: chair, manual. In manual mode, only commands from the steering will be executed; in char mode, the mobility will stay stationary.

4
USABILITY EVALUATION

4 USABILITY EVALUATION

4.1. Aim & Plan

We conducted a usability test using a working prototype to evaluate the validation of the Hug2Go concept in terms of safety, comfort, ease of use. In order to avoid unnecessary misunderstanding, we developed the usability test plan toolkit (Figure 25). It is a detailed document that describes everything from getting to the test venue to the exact words the test moderator will use. Through the usability evaluation, we aimed to ask as followings:

- Do people understand the value of Hug2Go?
- Do people understand how to select different kinds of modes?
- Do people understand how to use the hug steering?

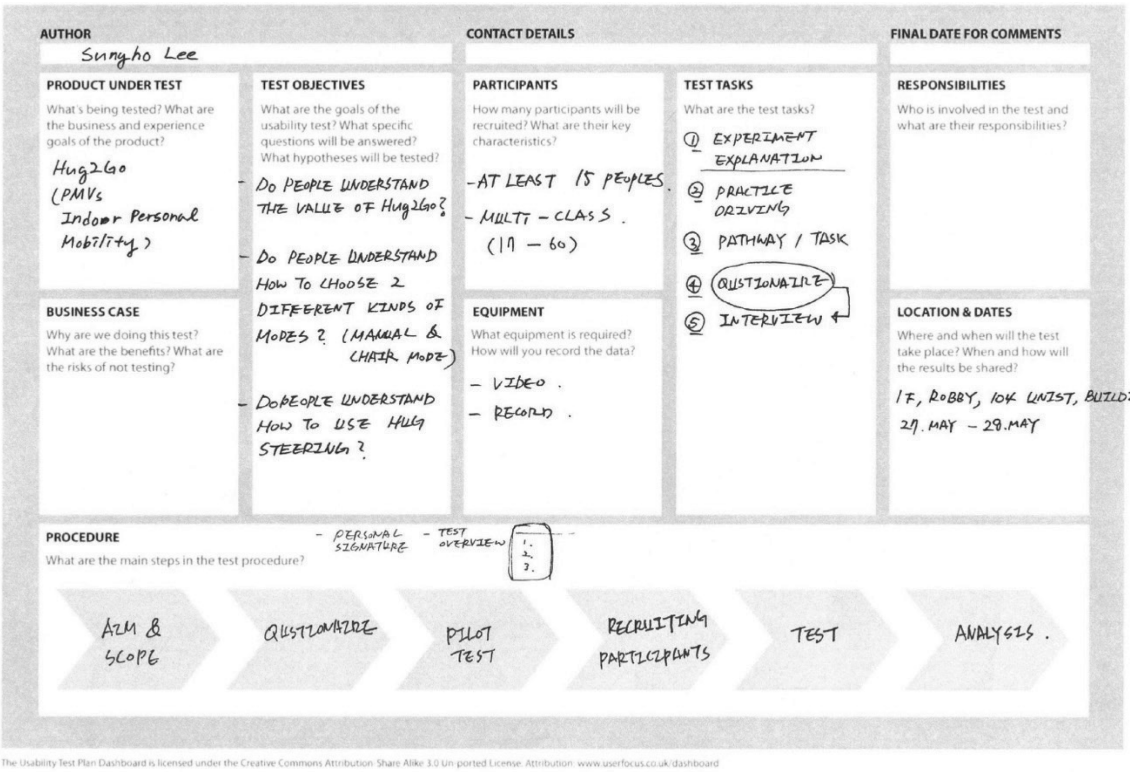


Figure 25. Usability test plan dashboard

4.2. Method

In order to usability evaluation, we used below test platform (Figure 26). In particular, we conducted MVP (minimum viable product), which is to provide feedback for product development. The seat and seat back are only designed and developed with the motor system to be verified from initial users.

Figure 26. Test platform (level 1)

4.2.1. Participants

The usability test was conducted with 15 people from 20 to 30 years old (8 males, 7 female). According to (Nielson, 1993), At least, 15 users are needed to discover all the usability problems in the design. It is probably possible to cover 100% of usability problems. Therefore, we recruited 15 peoples. The demography of the 15 participants are presented in Table 7 Overall, 53.3% of the participants were male, and 46.6% were female. The study group consisted of the followings: 15 persons (100%) are with ages 20-30. Overall, 33.3% of the participants have no experience of PMVs. 60% of the participants have a few times of experience. 0.6% of the participant only has lots of experience. Participants entirely are not aware of the existence of PMVs still.

Table 7. Demography of participants

Participants	Gender	Age	Experience of PMVs
P1	Male	20-30	Nothing
P2	Male	20-30	Nothing
P3	Male	20-30	Nothing
P4	Male	20-30	A few times
P5	Male	20-30	A few times
P6	Male	20-30	A few times
P7	Male	20-30	A few times
P8	Male	20-30	A few times
P9	female	20-30	Nothing
P10	female	20-30	A few times
P11	female	20-30	Nothing
P12	female	20-30	A number of experience
P13	female	20-30	A few times
P14	female	20-30	A few times
P15	female	20-30	A few times

4.2.2. Experimental procedure

Figure 27. displays a timeline view of the usability test. Participants required to be informed about the task before the usability test. First, the facilitator previewed experiment explanation. Particularly, participants were able to understand the main concept of Hug2Go. Second, participants spent enough time to practice driving. We demonstrated how to use the hug steering before manual trials for participants. Third, participants started to operate Hug2Go by themselves. Then, we gave the essential and formative information related to steering. Participant carried out manual trial. They move along the driving route (Figure 28). Previously, we consider the pathway where participant drives safely. Finally, participants take in a survey concerning the acceptance of Hug2Go and discuss it through the interview.

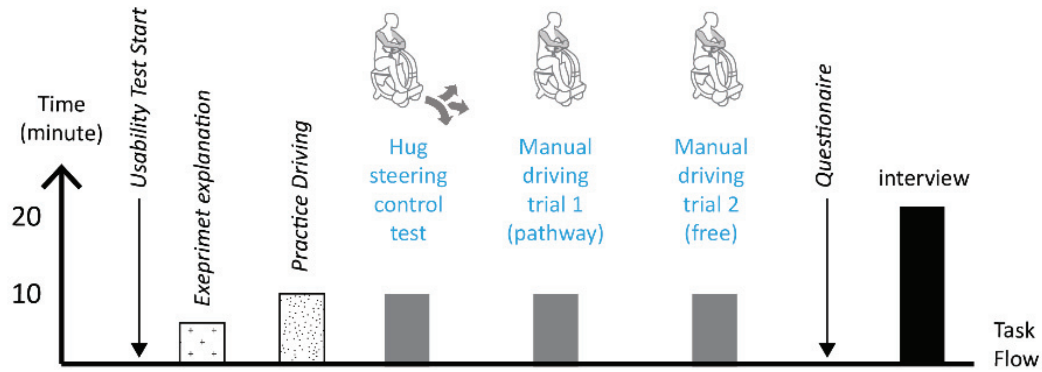


Figure 27. The process of usability test

Above mentioned in Chapter 3.1, we are targeting huge indoor space. Therefore, the 1F lobby, which is located in UNIST (approximately the area of 3600m2)is regarded as enough huge indoor space (Figure 9).

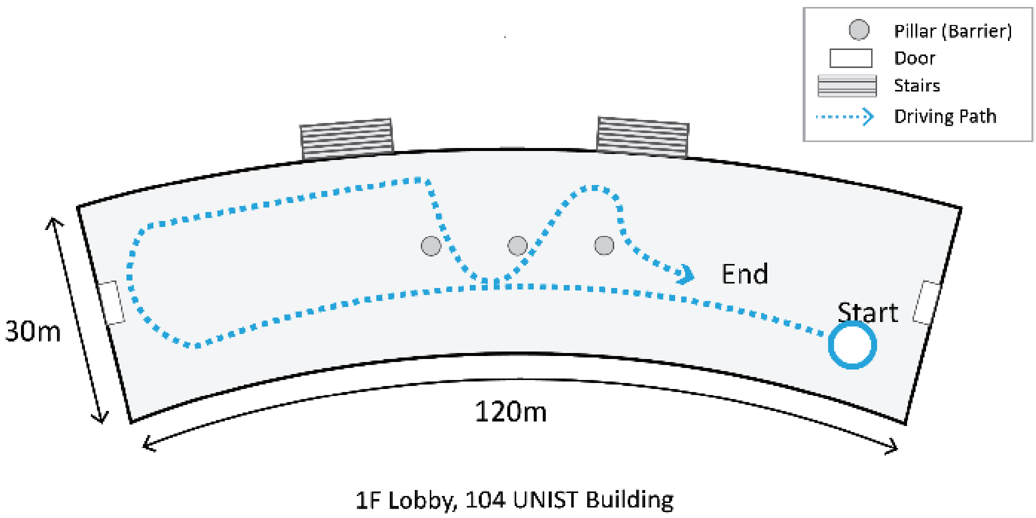


Figure 28. The pathway of driving test

Figure 29. Manual driving in the usability test

4.2.3. *Experimental design*

The user evaluation measured the participant's perception of the Hug2Go in terms of safety, comfort, ease of use. Comfort was defined as the quality of ride and seated well-being: Safety was defined as the user's level of control of the hug steering and his/her feeling of stability when driving the Hug2Go. We referred to a driving assessment tool to conduct user evaluation in terms of indoor personal mobility. The PMCDA developed by (Karamaj, 2014) was a validated training method for a power wheelchair. The PMCDA tool was used by a clinician who assessed the participant's driving skills in a scale 1 to 3 in the area of adequacy-efficacy (AE) and safety. The questionnaire (Appendix C) was modified to fit the tasks of the indoor spaces through PMCDA (Appendix B). Each measurement used a Likert scale of 1-5 where a score of 1-strongly disagree, 2-disagree, 3-neutral,4-agree, 5-strongly agree (Table 8). he total score was collected by the session of the questionnaire.

Table 8. Likert scale scoring

Strongly Disagree (전혀 아니다)	Disagree (아니다)	Neutral (잘 모르겠다)	Agree (그렇다)	Strongly Agree (매우 그렇다)
1	2	3	4	5

4.3. Results

4.3.1. Usage Intention of Hug2Go

The summary of usage intention of Hug2Go is in Table 9. Among the respondents, 15 respondents (100%) preferred the Hug2Go for moving within a building. Moreover, eight respondents (53.5%) believed that the Hug2Go could be used by disabled or .35) older people. Furthermore, five respondents (33.3%) preferred the Hug2Go for accessibility between home and nearest station and going shopping in the neighborhood. On the other hand, only one respondent (6.6%) thought the Hug2Go was available to go business travel in the urban area.

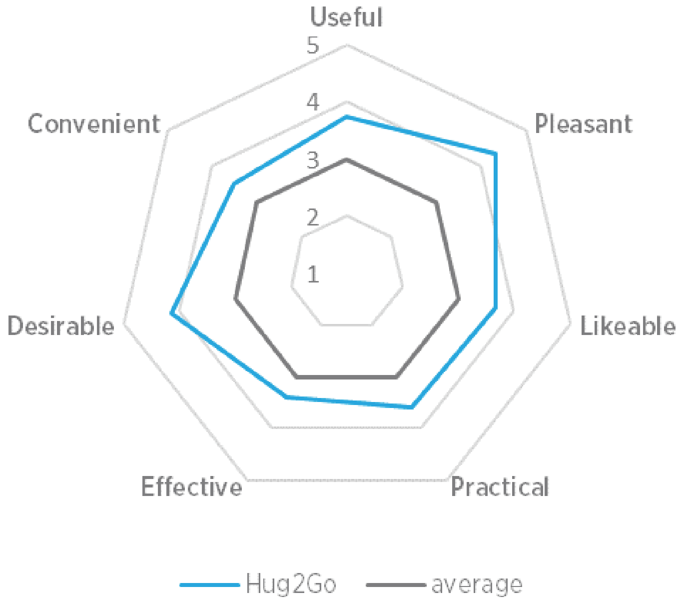
Additionally, no respondent believes that medium-distance commute or daily transport in an urban area. The survey results show in Table 9. indicate significantly valid for indoor mobility. All respondents preferred for moving within a building. However, 20-30 ages of the respondents only participated in this usability test. After recruiting multi-class people, this study is needed for validation.

Table 9. Respondents' usage intention of the Hug2Go *(n* = 15)

Usage Intention	Frequency	Percentage (%)
Moving within a building	15	100
Transport support for disabled or elderly people	8	53.3
Access between home and the nearest station	5	33.3
Shopping in neighborhood	5	33.3
Short-distance trip in downtown area	4	26.6
Extended travel ranges as a substitute	4	26.6
Access between destination and train station/ bus stop	3	20
Going to the neighborhood hospital	3	20
Touring and excursions	2	13.3
Business travel in urban area	1	6.6
Medium-distance commute	0	0
Daily transport in urban area	0	0

*The respondent is available for multiple selections

4.3.2. Acceptance of the indoor PMVs



Factors	Mean	σ
Pleasant	4.3	0.88
Desirable	4.1	0.61
Useful	3.7	0.97
Likeable	3.6	0.82
Practical	3.6	0.73
Convenient	3.5	0.35
Effective	3.4	0.99

Figure 30. Acceptance of Hug2Go (*n*=15)

The seven factors used to assess the respondent's judgment. The significant logical factors can influence acceptance of PMVs (Ando 2013). The value is regarded as the average of scoring (n=15, Likert scale of 1-5). As mentioned Sect. 4.2.3. The total score was used a Likert scale of 1-5 (Appendix B.).

Figure 30 shows the result in terms of acceptance. Overall, the seven factors are more than the average value of 3. It indicates that respondents are impressed by Hug2Go as acceptable indoor mobility entirely. In particular, "Pleasant" and "Desirable" are highly scored in these factors. On the other hand, "Convenient" and "Effective" are lower compared with other factors.

4.3.3. Usability of manual driving

We aimed at evaluating the hug steering through a usability test of manual driving. Before the usability test, we encouraged participants to drive the Hug2Go by themselves. During the manual driving (1,2 loops), participant evaluates the usability of the Hug2Go. Appendix D. shows that the average of the score is lower than score four overall. It indicates that participants were not satisfied with the manual driving remarkably. The lack of satisfying response could be due to the control system is not optimized. On the other hand, the usefulness of the indoor is adequate for participants. Furthermore, Q 3.11, Q 3.3, Q 3.8, Q 3.10 show the score of more than 3 (Appendix D. The mean of usability test (*n*=15, Maximum score 5)).

Figure 31 describes the acceptance of Hug2go from Appendix D. It shows three kinds of responses: disagree, neutral and agree.

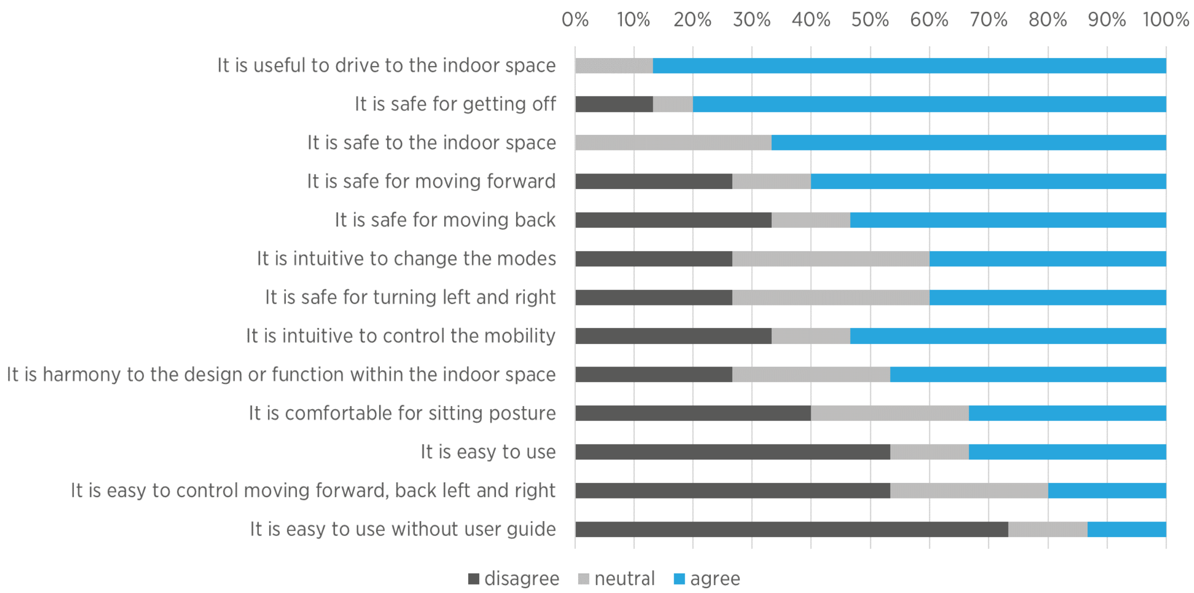


Figure 31. Acceptance of Hug2Go (n = 15)

4.3.4. Interview

We used interviews to collect rich insights. The interviews were initiated by asking several questions in terms of usability of the hug steering and acceptance of the concept. After that, we discussed the major problems and pains. The interview is a 20 to 30 min, semi-structured interview that assesses the Hug2Go users' participation in activities. Besides, we conducted all the interviews face-to-face individually. The category for this interview consisted of five types of entities: the hug steering, seat, and seat back, safety, aesthetic, others. They represented control, design, functional requirements. After completing the 15 interviews, the research team transcribed and translated the voice recordings. We constructed the significant findings based on classification — the process of transcribing, translating resulted in the identification of 5 entities (Table 10).

First, many of interview response reveals the difficulty of operation. In particular, when participants meet the first impression, many participants are confused about identity weather chair or mobility. Second, the participants did not sit back fully, leaning on the seat back. It is a different result expected. They want seat soft and more comfortable. Third, speed is suitable for indoor mobility. The participant mentioned that a reason would be due to the accident with a pedestrian caused by fast speed. Also, they want to stop in the emergency. Fourth, a more familiar design is needed for harmony with the indoor environment. Finally, one of the participants suggests the stop station rather than self-driving. In details, as following:

1) The hug steering

2) Seat and seat back

3) Safety

4) Aesthetic

5) Others

Table 10. The category of interview responses

Category		Interview responses
The hug steering	*P01*	*"I was confused as to whether it was a seatback or a controller. I thought of it as a steering wheel."*
	P01	*"I hope it's easy to go forward and turn left or right simultaneously."*
	P04	*"I didn't expect to use it before I see it. I was surprised that the seat back is a controller"*
	P05	*"If I keep turning in the floor, I feel dizzy. The chair is hard, so I feel uncomfortable."*
	P06	*"I need significant physical load when I control the hug steer."*
	P06	*"First boarding – the control is not as easy as I though before. Second boarding – it's fun to learn how to operate"*
	P06	*"It is difficult unless you explain the way of control."*
	P07	*"It is a lack of affordance. I hope the feeling of hug as being inside come to volume."*
	P08	*"It's easy to learn but It is difficult to recognize how much force to turn."*
	P13	*"It's difficult to operate it."*
Seat and Seat back	*P01*	*"It was uncomfortable to sit with your back full"*
	P01	*"It was uncomfortable to sit with seat back. I'm afraid of moving when I sit down."*
	P01	*"If you had a handle or something, it would be better. I wouldn't have to look back when I went back."*
	P03	*"Hard seat" , "It is irritating on pedestrian's eyes"*
	P04	*"The usage was not easy. It was far from the chair."*
	P05	*"I don't know where to sit. Feel uneasy sitting down"*
	P07	*"when I sit – I thought the curves would be good for sitting. But It was slipped. When I drive, the foot rest were convenient."*
	P08	*"It's inconvenient to sit on the floor. You don't have to use your seat back"*
	P08	*"I hope the seat is soft. I felt like sitting on a structure. It would be better if it was leather seat."*
	P10	*"the process of use is not difficult. There is an uncomfortable side to sit back."*
	P10	*"It is hard for women to get on board because of their skirts."*

	P11	*"The chair is hard. Difficult to operate, the seat back is not intuitive. It seems an inappropriate mode of operation for women."*
	P11	*"The armrest is needed."*
	P12	*"The seat back is too far"*
	P13	*"I hope it's more soft. It's very slippery."*
Safety	*P05*	*"It was good to move slowly in the indoor space. I want to keep riding because I like it."*
	P05	*"It was safe braking because I can get off whenever I'm in dangerous situation."*
	P12	*"It's dangerous if your knees come forward."*
	P04	*"I wish stop button or seat handle."*
	P05	*"I trust power on/off button. I hope familiar and safe design."*
	P08	*"If I moved back, it would sound"*
	P10	*"Pedestrian want to know the location of mobility through indication of lights or sound. It will be better to stop near the pedestrian even though you didn't perceive the pedestrian on driving.*
Aesthetic	*P06*	*"It's scary because of the steel frame."*
	P11	*"It new but unfamiliar. The part of carbon is not suitable."*
	P13	*"you need to choose bright color. It must not be a wheelchair design."*
Others	*P07*	*"If you considered the curve design of seat rather than the cushion. It is better to the stop station. I hope there was container for load. I need an emergency brake button."*

4.4. Findings

4.4.1. Valid PMVs for the indoor space

Interestingly, a hundred percentage participant agrees with the acceptability of indoor mobility (Table 9). Moreover, among the respondents, 13 respondents (86.6%) responded that it is useful to drive to the indoor space (Appendix D). Regardless of the low fidelity of the platform, most of the respondent thought that it is highly validated for the indoor space.

4.4.2. Incomplete manual steering structure

Eleven respondents (73.3%) responded that it is not easy to use without the user guide. Furthermore, eight respondents (53.3%) disagreed that it is easy to control moving forward, back, left, and right. On the other hand, P08 mentioned, “it is easy to learn” and a half of respondents felt that it is intuitive to control the mobility (Appendix D). Therefore, hug steering is somewhat unclear. It could be due to incomplete manual steering structure.

4.4.3. Not easy but pleasant

Appendix D. shows the significantly counted negative feedback is to control the hug steering. As mentioned in 4.4.2, It depends on the fidelity of the hug steering. However, generally, the participants enjoyed the Hug2Go, as evidenced from many indicating that they would want to ride the Hug2Go again in the future and comments on surveys such as “*fun*” or “*awesome*”.

4.4.4. Correlation component with acceptance through Factor analysis

For the acceptance of the indoor PMVs, factor analysis was used to describe variability among observed, correlated variables in terms of a potentially. The goal of this analysis was to build a correlation between the factors.

The seven-factor used to assess the respondents' judgments about the PMVs. A Kaiser normalization was performed to define the components in terms of subsets, as shown in Figure 30. The first subscales, termed practical, useful, effective could be interpreted as the Base1 of a system. The second set of subscales, termed convenient, likable, could be interpreted as reflecting the Base2 with a system. The third is pleasant. The fourth is desirable.

On the other hand, in Appendix D the mean scores for practical and effective are much less than others. It indicates that the test platform provides enough usefulness to users.

Table 11. The result of factor analysis

	Base1	Base2	Base3	Base4
Practical	0.949	0.076	-0.017	-0.006
Useful	0.916	0.060	-0.097	0.176
Effective	0.816	0.299	0.204	0.248
Convenient	0.007	0.974	-0.053	0.022
Likable	0.423	0.808	0.274	-0.103
Pleasant	-0.003	0.071	0.983	-0.108
Desirable	0.192	-0.040	-0.116	0.968

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. a. Rotation converged in 5 iterations.

4.4.5. Insights through interview

After completing the 15 interviews, the research members reviewed and interpreted with the interview. We constructed significant insights based on sorting. The process of transcribing, translating resulted in the identification of several categories as followings:

4.4.6. Recognition of moving reverse

The participant is not used to operating the hug steering yet. They are used to operating existing mobility. A participant did not recognize reversing function by the end. It could be because of no reverse function in the existing PMVs.

4.4.7. A lack of the steering feedback

The hug steering is no feedback with a level of control. It only depends on the driver's control. Typically, the controller has such an indicator. For example, throttle or joystick enables users to recognize the degree of control through physical feedback.

- P08 commented, *"easy to learn, but It is difficult to recognize how much force to turn."*

4.4.8. Emergency button and pedestrian verification

The Hug2Go has a function of reverse moving. During the reverse moving, a passenger could not recognize the pedestrians. Therefore, we consider the interaction between pedestrian and passenger. Also, in order to avoid an emergency, users want to stop immediately.

- P04 commented, *"I wish stop button or seat handle."* and P05 said, *"I trust power on/off button. I hope familiar and safe design."*

- P8 and P10 said, *"If I moved back, it would sound" and "Pedestrian want to know the location of mobility through the indication of lights or sound. It will be better to stop near the pedestrian even though you did not perceive the pedestrian on driving."*

More, the participants also reported that the highest levels of discomfort and fear without the assistance system ate the high pedestrian density.

4.4.9. Uncertain affordance (Hug vs. Hold)

We observed a various type of motion to control the hug steering. It indicates uncertain affordance of steering control.

- P01 addressed, *"I was confused as to whether it was a seat back or a controller. I thought of it as a steering wheel."*
- P04 described, *"I did not expect to use it before I see it. I was surprised that the seat back is a controller"*

Figure 32. A various types of motion

4.4.10. Adjusting seat and seat back height or posture

Probably, the user's height or posture might affect the performance of the hug steering. It could due to the form of mobility. The Hug2Go follows general chair form. Consequently, a user's height or position will be designed parameter.

- P01 said, *"It was uncomfortable to sit with your back full" and* P12 said *"The seat back is too far."*
- P05 commented, *"I do not know where to sit. Feel uneasy sitting down."*

4.4.11. Enhancing convenience

- P07 addressed, *"I hope there was a container for the load."*

5

DISCUSSION

5 DISCUSSION

This study explored the utility and usage of the new types of PMVs in the context of a realistic indoor driving task, in order to assist with the acceptance of PMVs and characterization selection. We intended for this work to be an initial step for further investigation on the topic of the indoor PMVs, as there is not much existing literature regarding design and acceptance of the indoor driving.

In this chapter, we discussed several following topics from findings in usability evaluation. Also, we addressed the limitation of the study.

5.1. Discussion

5.1.1. Validation of the indoor PMVs

We suppose a new model of indoor mobility and examine it possible to build on the market through usability evaluation. Interestingly, all participants respond to high validation of the indoor mobility concept. Even though we used a low-fidelity platform, the results regarding validation can be meaningful. Besides, participants experienced indoor driving for the first time. The new experience could give a pleasant impression. It probably could be latent needs for users. However, it is uncertain whether responses are purely due to latent needs or not. In the context of our experiment, participants are unable to encounter the real situation naturally. Therefore, additional experimentation should be conducted, such that long-term experiment concerning real-life.

5.1.2. Hug vs. Hold

We provide a new way of steering. It contains motion of hug. A variety of ways is considered before creating a concept. The conventional steering method is not entirely suitable for the indoor mobility such as throttle or lever and joystick etc. we choose the new of steering users to make it easier to manipulate it. Everyone is familiar with the chair. Our approach is to sit on the chair facing in the opposite direction. People usually lean their backs against the backrest and their legs forward. Instead of usually sitting in the chair, people sometimes will turn the chair around and place legs on either side of the chair, typically using the back of the chair as an armrest. We interpreted one of the affordances. The objects could tell us what they are for (Gibson, 1977). Through ideation and visualization, we provide the hug steering. The backrest becomes the operating control during manual operation. The purpose of looking at how people to use the backrest was to determine which form would be useful at manual driving.

In the experiment, it was a different result than we had expected. Participants preferred to hold backrest that to hug it, and many motions were found. It probably indicates two perspectives. First, the loss of controllability is a reason to hold backrest. The hug steering is not optimized to everyone. Figure 32 shows different control points from the user's height or size. It is a similar characteristic with the chair. Second, it is due to uncertain affordance. Typical backrests are optimized for users to lean on their backs. On the other hand, the backrest of the Hug2Go should be able to hug by the users. The cross section is in a concave shape. However, the convex shape is more suitable for the user to be able to hug.

5.1.3. Identity of Hug2Go (chair + mobility vs. mobility with chair)

The design of the Hug2Go is an approach to integrate chair and mobility. The idea of using multiple functions is to improve the value. However, users were confused about multi-functional several components. A participant was aware of chair overall and want seat rest for comfortability. The backrest is multi-functional. Participants sit back with backrest entirely for the first time. However, they are unconsciously scared or discomfort after driving. It probably might figure out steering function from driving. Figure 33 show correlation of tradeoff between chair and mobility.

Therefore, we need to define the identity of Hug2Go. First, the chair mode is not sitting for a long-term. Sometimes, physical tension people, are aware of can be really exhausted in the huge indoor spaces. Then, the user can use chair mode for short-term until the user recovers their tension. Second, Hug2Go has enhanced mobility with the function of the chair. Thus, several functions of chair remove such as armrest, rotation of seat, etc.

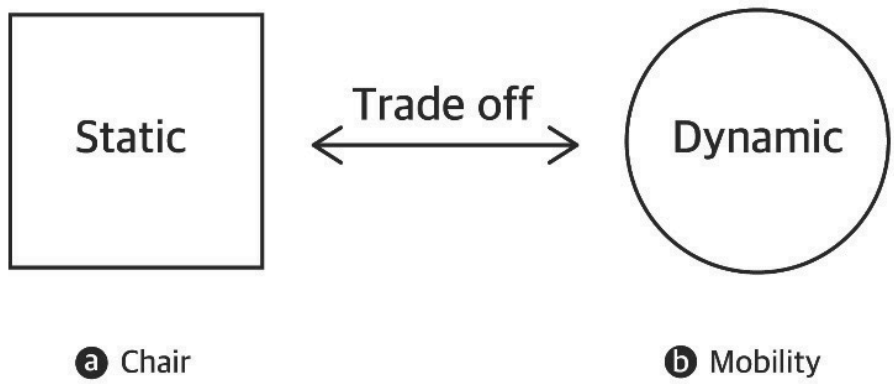


Figure 33. Characteristic of product, (a) Chair, (b) Mobility

5.1.4. Opportunities for improvements

From the above discussion, it is apparent that Hug2Go should focus on the attribute of the Hug2Go that are related to functions and design (Yang, 2013). These opportunities for improvement are shown schematically in Figure 34. As shown in the diagram, (b), (c) which are all 'high value added.' Concerning attributes (d), (e), (h), (j), (k), (l), which are 'necessary' respectively, the Hug2Go can reduce the level of fulfillment.

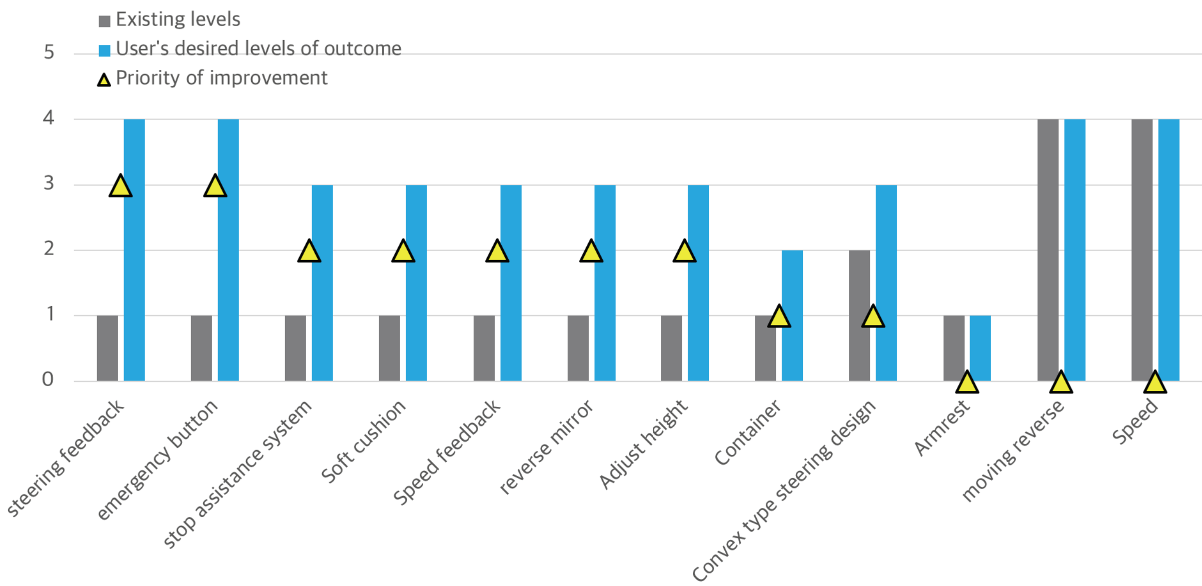


Figure 34. Opportunities for improvements in the attributes of product

5.2. Limitation

5.2.1. Multi-class test

Due to the immature/growing development of PMVs, there is little work regarding multi-class passenger while riding or such system. Similarly, there is less related work using elderly/disabled users and children. We targeted multi-class at first. It is uncertain whether responses are purely due to latent needs or not. In the context of our experiment, participants are unable to encounter the real situation naturally. Therefore, additional experimentation should be conducted

5.2.2. Controllability of steering

The current mechanical designs and control algorithms of Hug2Go restrict comfortable users' steering. This problem is associated with mechanical structure, electronic, control algorithms, and other parts. It effects on usability evaluation. In the next research, we improve excellent controllability and material (Figure 25).

5.2.3. Incomplete implementation

The purpose of this research is to provide design-driven perspective form. This study has some limitation that the implementation is incomplete. It is still low-fidelity. The bias and hesitations of respondents affect the analysis of the survey. The further research may be conducted to implement engineering and design.

5.2.4. Vacancy of sharing model and benefit of sharing

Hug2Go allows individuals access to the PMVs by joining a service that maintains a bunch of PMVs at various indoor locations. Apparently, the current scooter sharing models can include a variety of motorized and non-motorized scooter types. The sharing service provider typically provides gasoline or charge. Therefore, service models are beginning to emerge that recognize the various needs of passengers.

6

CONCLUSION

6 CONCLUSION

6.1. Conclusion

This study set out to investigate how to design indoor PMVs. In order to research these four research questions were constructed: what is the primary barrier into inner space apply existing mobility? What is the new design of indoor personal mobility? How is the acceptance of the indoor PMVs? What are the implication for the indoor PMVs?

The main findings from this study suggest that the indoor PMVs is acceptable for all participants, it could be due to latent needs, and Overall, the seven factors are more than the average value 3. This indicates that respondents are impressed by Hug2Go as acceptable indoor mobility entirely. In particular, “Pleasant” and “Desirable” are highly scored in these factors.

Interestingly, the seven-factor used to assess the respondents’ judgments about the PMVs. A Kaiser normalization was performed to define the components in terms of subsets, as shown in Figure 30. The first subscales, termed practical, useful, effective could be interpreted as the usefulness of a system. The second set of subscales, termed convenient, likable could be interpreted as reflecting the satisfaction with a system.

This may mean that Hug2Go need to improve performance concerning usefulness. There are many suggestions that this study can make in order to improve functional performances. First, we defined the identity of Hug2Go. Hug2Go is the indoor personal mobility with the chair. Moreover, we discovered opportunities for improvement through usability evaluation and interview.

Finally, we hope this work to be an initial step for further investigation on the topic of the indoor PMVs, as there is not much existing literature regarding design and acceptance of the indoor driving.

6.2. Further works

6.2.1. Optimizing System

In future research, several issues need to be addressed before indoor PMVs are introduced. First, we plan to improve the controllability of the current platform and develop the self-driving concept level 2. We would also consider deploying and testing them in more challenging environments with narrow and crowded pathways over a prolonged period.

6.2.2. Validation of Hug2Go indoor area

In particular, the acceptance of the indoor PMVs is uncertain whether responses are purely due to latent needs or not. In the context of our experiment, participants are unable to encounter the real situation naturally. We can conduct field research and survey in our target such as, COEX, BEXCO and KINTEX. Therefore, additional experimentation should be conducted, such that long-term experiment concerning real-life.

6.2.3. Interaction between driver and pedestrian

Furthermore, we should study a relationship or interaction between driver and pedestrian. During the driving experiment, the passenger could not recognize the pedestrians. Therefore, we consider that the interaction between pedestrian and passenger is substantial research issues.

6.2.4. Development of services & business model for Hug2Go

The more people use shared modes, the more likely they are to use public transit, own fewer cars, and spend less on transportation overall. Lifestyle also changes that occur people begin to use shared-use mode. Therefore, the indoor mobility probably will need infrastructure of the shared service. For example, the charging station is enhancing for self-driving mode. Moreover, Hug2Go service support opened app or web-based reservation system for customers who want to use convenient mobility in the huge space such as, airport, convention center and malls. Consequently, we hope considering eco-system and niche service as well development in the next research(Figure 35).

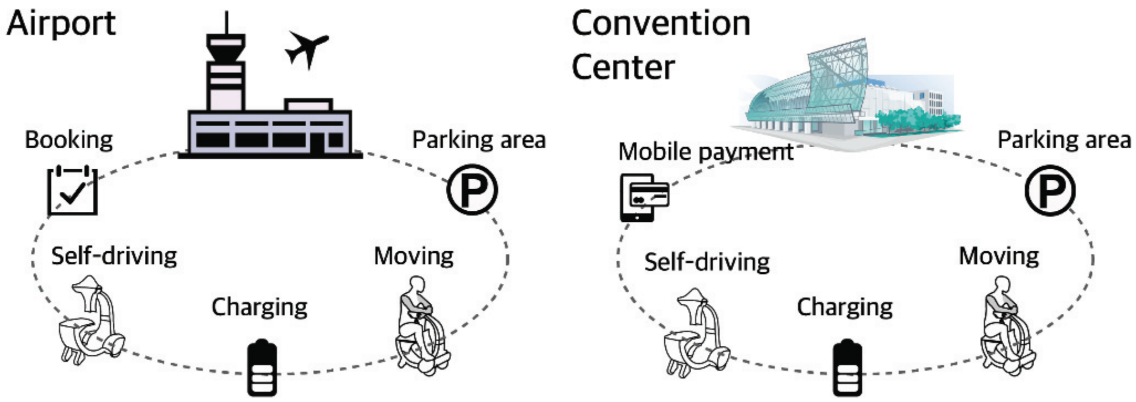


Figure 35. The example of Hug2Go service

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Appendices

Appendix A. Modified Power-Mobility Community Driving Assessment(PCDA)

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4.5km

Feb 10, 2019

Observation (Experience Simulation, Field Activity)

OVERVIEW

Background

Project 4.5km focus on discovering opportunity and design new future mobility concepts for people who use indoor shared mobility. With observations, 4.5km would like to further more refined concepts for users.

APPROACH

Step A

Observe users

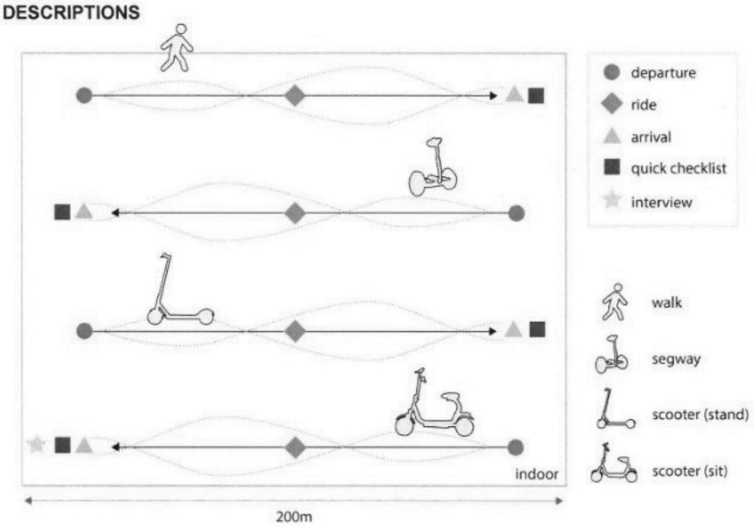
1. Follow the flow
2. Quick Checklist

Step B

Interviews

1. Interviews
2. Quick debrief

DESCRIPTIONS



1. Follow the flow

(you could memo below / look for the following occurrences)

- Routines
- Interaction
- Interruptions
- Shortcut/workarounds
- Contexts
- Habits
- Rituals
- Jargon
- Annoyance
- Delights
- Transition
- Artifacts

2. Quick Checklist

1) Safe

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. 탑승 시 안전하다	1	2	3	4	5
2. 주행 중 안전하다	1	2	3	4	5
3. 하차 시 안전하다	1	2	3	4	5
4. 충전 시 안전하다	1	2	3	4	5

2) Intuitive

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. 제어 및 조작이 간편하다	1	2	3	4	5
2. 엑셀과 브레이크 구분이 쉽다	1	2	3	4	5
3. 충전 포트 찾기가 쉽다	1	2	3	4	5
4. 형태에 따른 기능이직관적이다	1	2	3	4	5

3) Universally Accessible

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. 어린 아이가 조작 간편하다	1	2	3	4	5
2. 노인이 조작하기 간편하다	1	2	3	4	5
3. 장애인이 조작하기 간편하다	1	2	3	4	5
4.	1	2	3	4	5

4) Efficient

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. 실내에서 효율적 이동이 가능하다	1	2	3	4	5
2. 속도 조절과 정지 등 조작이 효율적이다	1	2	3	4	5
3. 충전 방법이 효율적이다	1	2	3	4	5
4. 보관이 용이하다	1	2	3	4	5

5) Fun

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. 주행이 즐겁다	1	2	3	4	5
2. 조작이 즐겁다	1	2	3	4	5
3.	1	2	3	4	5
	1	2	3	4	5

6) Look & Feel

Attractive								Ugly
Clear								Confusing
Dull								Colorful
Exciting								Boring
Annoying								Pleasing
Helpful								Unhelpful
Poor								Well designed

3. Power-Mobility Community Driving Assessment(PCDA) , Driving Assessment Forms

1) SECTION A-Mobility and Driver Experience Checklist

A1. ASSESSMENT

Date: ______________ Time: ______________

A2. PERSONAL-MOBILITY DRIVING EXPERIENCE

Years driving an automobile or other vehicle *(specify)* ______________________________

Years driving an personal mobility ______________________________

Personal mobility training received (dates & duration) ______________________________

Devices used ______________________________

Environments ______________________________

A3. MOBILITY DEVICE FACTORS THAT MAY AFFECT DRIVING PERFORMANCE
Examine the driving device and check if the factor appears to be acceptable for safe, efficient driving.

Chair Alignment	☐	Tire Tread Pattern	☐
Parallel Wheels	☐	Adequate Tire Inflation	☐
Straight Forks	☐	Tire Diameter & Width	☐

Comments: ______________________________

A4. MOBILITY DEVICE GENERAL USE

	YES	NO
Use speed control?	☐	☐
Utilize braking system?	☐	☐
Disengage braking system?	☐	☐
Use special features of devce?	☐	☐
Find charging system?	☐	☐

2) SECTION B- Pre-Performance Interview

B1. LIFESTYLE ANALYSIS

Identified Environments	Possible Environmental Obstacles
1. ______________	______________________
2. ______________	______________________
3. ______________	______________________

B2. DRIVER FACTORS THAT MAY AFFECT DRVING PERFORMANCE

1.	Is the driver able to sit/standing with stability and use the controls?	YES	☐	NO	☐
2.	Is the driver's sitting/standing tolerance adequate for assessment & intended uses?	YES	☐	NO	☐
3.	Is the driver positioned optimally?	YES	☐	NO	☐
4.	Does the driver have adequate sensation & perception to handle the device?	YES	☐	NO	☐

B3. EMERGENCY SITUATIONS

1. What would you do if your mobility wouldn't start and stop? ____________________

____

2. What would you do if you were out and you had a flat tire? ____________________

____

3. What would you do if you lose balance of mobility? ____________________

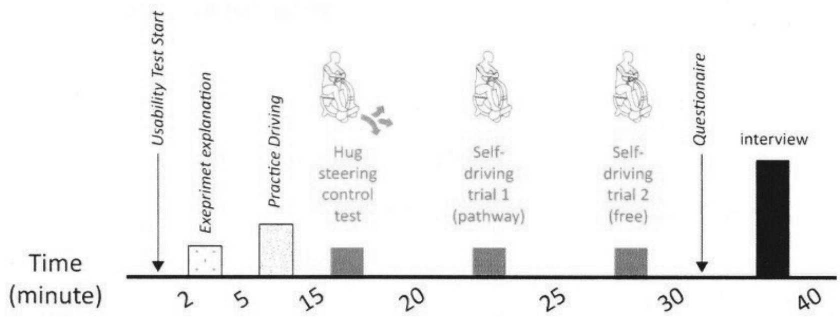
____

Appendix B. MODIFIED PMCDA DRIVING EVALUATION

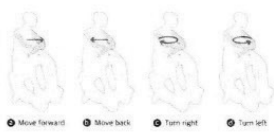
Hug2Go : The Indoor Smart Driving Mobility

Hug2Go 는 유동 인구가 활발한 옥내 2000m² 이상에 면적의 공용 공간 에서 운행 가능한 공유형 실내 스마트 모빌리티 입니다. 코엑스나 킨텍스 같은 전시회장 또는 롯데월드 타워/몰, 스타필드 하남과 같은 복합몰에서 비교적 걷기에는 먼 거리를 Hug2Go를 통해 이동할 수 있습니다.

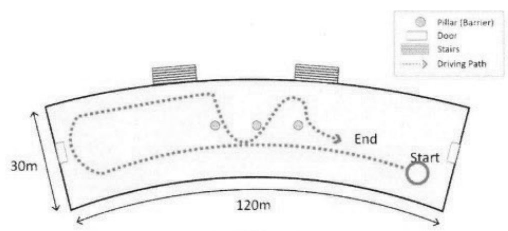
이번 실험에서는 개발된 모빌리티를 사용자가 실내공간에서 타면서 느끼는 주행 경험과 감정을 조사하고자 합니다.



Hug steering control test.



Self-driving



1F Robby, 104 UNIST Building

USABILITY TEST for Hug2Go

Date :

Time :

Gender	Age	Experience of PMVs
□ Male	□ less than 10	□ nothing
□ Female	□ 11 - 20	□ A few times
	□ 21 - 30	□ A number of experience
	□ 31 - 40	
	□ 41 - 50	

1 What place is suitable for Hug2Go? (Hug2Go 가 적합한 환경을 고르세요, 중복 가능)

- ☐ Touring and excursions (짧은 여행 이나 투어)
- ☐ Short-distance trip in downtown area (시내 근거리 이동)
- ☐ Moving within a building (건물 내에 실내 공간)
- ☐ Access between home and the nearest station (집에서 근거리 역 까지 이동)
- ☐ Shopping in neighborhood (주변 쇼핑)
- ☐ Transport support for disabled or elderly people (장애인 또는 노약자의 이동)
- ☐ Access between destination and train station/ bus stop (정류장 간에 이동)
- ☐ Going to the neighborhood hospital (근처 병원)
- ☐ Extended travel ranges as a substitute (목적지 하차 후 근거리 이동)
- ☐ Medium-distance commute (출퇴근 중거리)
- ☐ Daily transport in urban area (대도시 대중교통)
- ☐ Business travel in urban area (대도시 업무 이동)

2 Look & Feel (제품에 대한 인상)

2.1 Useful (유용하다)

Strongly Disagree (전혀 아니다)	Disagree (아니다)	Neutral (잘 모르겠다)	Agree (그렇다)	Strongly Agree (매우 그렇다)

2.2 Pleasant (즐거운)

Strongly Disagree (전혀 아니다)	Disagree (아니다)	Neutral (잘 모르겠다)	Agree (그렇다)	Strongly Agree (매우 그렇다)

2.3 Likeable (호감이 가는)

Strongly Disagree (전혀 아니다)	Disagree (아니다)	Neutral (잘 모르겠다)	Agree (그렇다)	Strongly Agree (매우 그렇다)

2.4 Practical (실용적인)

Strongly Disagree (전혀 아니다)	Disagree (아니다)	Neutral (잘 모르겠다)	Agree (그렇다)	Strongly Agree (매우 그렇다)

2.5 Effective (효율적인)

Strongly Disagree (전혀 아니다)	Disagree (아니다)	Neutral (잘 모르겠다)	Agree (그렇다)	Strongly Agree (매우 그렇다)

2.6 Desirable (가치가 있는)

Strongly Disagree (전혀 아니다)	Disagree (아니다)	Neutral (잘 모르겠다)	Agree (그렇다)	Strongly Agree (매우 그렇다)

2.7 Convenient (편리한)

Strongly Disagree (전혀 아니다)	Disagree (아니다)	Neutral (잘 모르겠다)	Agree (그렇다)	Strongly Agree (매우 그렇다)

3 Usability

3.1 It is easy to use (이 제품은 사용하기 쉽다고 생각한다).

Strongly Disagree (전혀 아니다)	Disagree (아니다)	Neutral (잘 모르겠다)	Agree (그렇다)	Strongly Agree (매우 그렇다)

3.2 It is easy to use without user guide (사용법에 대한 가이드가 필요 없다).

Strongly Disagree (전혀 아니다)	Disagree (아니다)	Neutral (잘 모르겠다)	Agree (그렇다)	Strongly Agree (매우 그렇다)

3.3 It is safe to the indoor space (이 제품은 실내 공간에서 이동시에 안전하다).

Strongly Disagree (전혀 아니다)	Disagree (아니다)	Neutral (잘 모르겠다)	Agree (그렇다)	Strongly Agree (매우 그렇다)

3.4 It is harmony to the design or function within the indoor space (이 제품은 실내 공간과 디자인이나 기능이 조화롭다).

Strongly Disagree (전혀 아니다)	Disagree (아니다)	Neutral (잘 모르겠다)	Agree (그렇다)	Strongly Agree (매우 그렇다)

3.5 It is useful to drive to the indoor space (이 제품은 실내 공간에서 유용하다).

Strongly Disagree (전혀 아니다)	Disagree (아니다)	Neutral (잘 모르겠다)	Agree (그렇다)	Strongly Agree (매우 그렇다)

3.6 It is comfortable for sitting posture (앉아 있는 자세가 편안하다).

Strongly Disagree (전혀 아니다)	Disagree (아니다)	Neutral (잘 모르겠다)	Agree (그렇다)	Strongly Agree (매우 그렇다)

3.7 It is easy to control moving forward, back, left and right (주행 시 전, 후, 좌, 우 조향이 쉽다).

Strongly Disagree (전혀 아니다)	Disagree (아니다)	Neutral (잘 모르겠다)	Agree (그렇다)	Strongly Agree (매우 그렇다)

3.8 It is safe for moving forward (전진 시 안전하다).

Strongly Disagree (전혀 아니다)	Disagree (아니다)	Neutral (잘 모르겠다)	Agree (그렇다)	Strongly Agree (매우 그렇다)

3.9 It is safe for turning left and right (좌, 우 회전 시 안전하다).

Strongly Disagree (전혀 아니다)	Disagree (아니다)	Neutral (잘 모르겠다)	Agree (그렇다)	Strongly Agree (매우 그렇다)

3.10 It is safe for moving back (후진 시 안전하다).

Strongly Disagree (전혀 아니다)	Disagree (아니다)	Neutral (잘 모르겠다)	Agree (그렇다)	Strongly Agree (매우 그렇다)

3.11 It is safe for getting off (하차 시 안전하다).

Strongly Disagree (전혀 아니다)	Disagree (아니다)	Neutral (잘 모르겠다)	Agree (그렇다)	Strongly Agree (매우 그렇다)

3.12 It is intuitive to control the mobility (조향 방법이 직관적이다).

Strongly Disagree (전혀 아니다)	Disagree (아니다)	Neutral (잘 모르겠다)	Agree (그렇다)	Strongly Agree (매우 그렇다)

3.13 It is intuitive to change the modes (조작 모드 변경이 직관적이다).

Strongly Disagree (전혀 아니다)	Disagree (아니다)	Neutral (잘 모르겠다)	Agree (그렇다)	Strongly Agree (매우 그렇다)

Appendix C. Interview responses

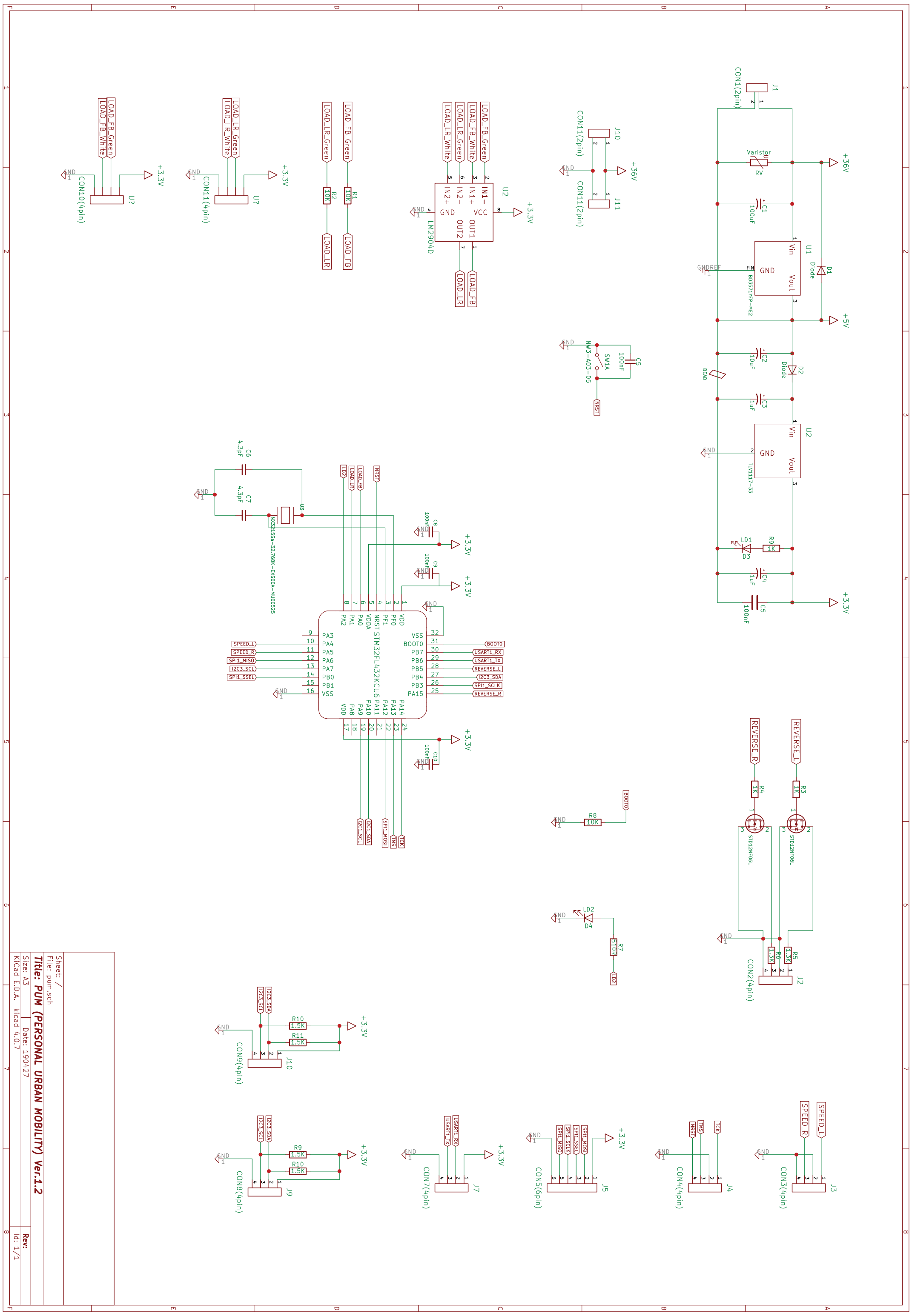
Q1. What are your impressions related to usage and journey of driving?	
P01	*"I was confused as to whether it was a seatback or a controller. I thought of it as a steering wheel."*
P01	*"It was uncomfortable to sit with your back full"*
P03	*"Hard seat" , "It is irritating on pedestrian's eyes"*
P04	*"I didn't expect to use it before I see it. I was surprised that the seat back is a controller"*
P04	*"The usage was not easy. It was far from the chair."*
P05	*"It was good to move slowly in the indoor space. I want to keep riding because I like it."*
P05	*"It was safe braking because I can get off whenever I'm in dangerous situation."*
P05	*"I don't know where to sit. Feel uneasy sitting down"*
P06	*"First boarding – the control is not as easy as I though before. Second boarding – it's fun to learn how to operate"*
P07	*"when I sit – I thought the curves would be good for sitting. But It was slipped. When I drive, the foot rest were convenient."*
P08	*"It's inconvenient to sit on the floor. You don't have to use your seat back"*
P10	*"the process of use is not difficult. There is an uncomfortable side to sit back."*
P11	*"The chair is hard. Difficult to operate, the seat back is not intuitive. It seems an inappropriate mode of operation for women."*
P12	*"The seat back is too far"*
P13	*"I hope it's more soft. It's very slippery."*
Q2. What is the most inconvenient part in the usage?	
P01	*"It was uncomfortable to sit with seat back. I'm afraid of moving when I sit down."*
P01	*"I hope it's easy to go forward and turn left or right simultaneously."*
P05	*"If I keep turning in the floor, I feel dizzy. The chair is hard, so I feel uncomfortable."*
P05	*"I need significant physical load when I control the hug steer."*
0P6	*"It is difficult unless you explain the way of control."*
P06	*"It's scary because of the steel frame."*
P07	*"It is a lack of affordance. I hope the feeling of hug as being inside come to volume."*
P08	*"It's easy to learn but It is difficult to recognize how much force to turn."*
P10	*"It is hard for women to get on board because of their skirts."*
P11	*"It new but unfamiliar. The part of carbon is not suitable."*
P12	*"It's dangerous if your knees come forward."*
P13	*"It's difficult to operate it."*
Q3. What is any opinions for the improvement?	
P01	*"If you had a handle or something, it would be better. I wouldn't have to look back when I went back."*
P04	*"I wish stop button or seat handle."*

P05	*"I trust power on/off button. I hope familiar and safe design."*
P07	*"If you considered the curve design of seat rather than the cushion. It is better to the stop station. I hope there was container for load. I need an emergency brake button."*
P08	*"I hope the seat is soft. I felt like sitting on a structure. It would be better if it was leather seat."*
P08	*"If I moved back, it would sound"*
P10	*"Pedestrian want to know the location of mobility through indication of lights or sound. It will be better to stop near the pedestrian even though you didn't perceive the pedestrian on driving."*
P11	*"The armrest is needed."*
P13	*"you need to choose bright color. It must not be a wheelchair design."*

Appendix D. The mean of usability test (*n*=15, Maximum score 5)

No.	Usability	Mean	σ
Q 3.5	It is useful to drive to the indoor space	3.9	0.46
Q 3.11	It is safe for getting off	3.9	0.96
Q 3.3	It is safe to the indoor space	3.8	0.68
Q 3.8	It is safe for moving forward	3.4	0.99
Q 3.10	It is safe for moving back	3.2	1.15
Q 3.13	It is intuitive to change the modes	3.2	0.94
Q 3.9	It is safe for turning left and right	3.1	0.83
Q 3.12	It is intuitive to control the mobility	3.1	1.25
Q 3.4	It is harmony to the design or function within the indoor space	3	1.20
Q 3.6	It is comfortable for sitting posture	2.9	1.10
Q 3.1	It is easy to use	2.8	1.25
Q 3.7	It is easy to control moving forward, back left and right	2.7	1.16
Q 3.2	It is easy to use without user guide	2.2	1.10

Appendix E. PCB Design



Executive Summary in Korean

Hug2Go: The Development of Indoor Smart Driving Personal Mobility

본 연구는 실내 공유형 모빌리티에 대한 사용자 수용성을 평가하고, 적합한 형태의 디자인 개발이 목표이다. 특히, 새로운 형태의 모빌리티 디자인과 제어 방법을 초기 연구 성과로 제시한다. Hug2Go 는 실내에서 자율 주행으로 탑승자를 찾고, 탑승자에게 친근한 의자 형태로 일시적인 휴식 공간을 제공한다. 또한, 탑승자는 수동 조작을 통해 넓은 실내 공간에서 목적지까지 이동이 가능하다. 그 동안 미래형 교통 수단으로 다양한 형태의 개인형 모빌리티 (PMVs, Personal Mobility Vehicles) 가 제안 되어 왔다. 기존의 차량과 달리 전동식 모터로 구동하는 PMVs 는 근거리 이동에 편리함을 제공할 뿐만 아니라, IT, 센싱, 전동력을 적용하여 휴대성과 이동 시 안전 및 편의를 갖추고 있다는 특징을 가지고 있다. 따라서 PMVs 는 기존 차량의 시스템 문제들의 해결방안이 될 수 있어 최근 들어 많은 제품들이 개발 및 출시 되고 있다.

하지만, 지금까지 대부분의 PMVs 연구는 상용화된 실외형 기준으로 외형 디자인 개발과 동작 제어 설계로 치중되어 있다. 따라서, PMVs 에 대한 소비자들의 관심이 증가할수록 공공 영역이나 넓은 실내에서 사용하는 모빌리티의 안정성과 제어 방법에 대한 연구의 필요성을 예상된다. 우리는 특히, 대규모 전시회장이나 이동이 필요한 공항 같은 넓은 실내 공간을 기회 영역으로 삼고 본 연구를 진행하였다. 개발에 앞서 기본 실외형 모빌리티를 실내에 도입했을때 생기는 문제점을 발견하고, 실내형 모빌리티에 대한 수용성에 대한 정성적인 조사를 진행하였다. 둘째, 새로운 형태의 실내형 모빌리티 디자인을 제안하고 개발하였다. 셋째, 개발된 모빌리티를 통해 실내 환경에서 수용성 조사를 진행 하였다.

결과를 통해, 실내 환경에서 새로운 유형의 실내형 모빌리티에 대한 수용성은 긍정적으로 평가 되었다. 그러나, 제안된 hug steering 의 제어 방법은 사용자가 직관적으로 제어하기는 어려운 방법으로 파악되었다. 이는 직관성이 부족하기도 하지만, 구현이 충분치 않은 점도 작용하였다. 반면, 제어 방법이 쉽지는 않지만, 전반적으로 사용자들이 모빌리티 주행이 즐겁다는 의견을 주었다. 이러한 점은 차기 개발 제품에도 반영될 필요가 있다.

다음 연구에서는 사용성 평가를 통해 발견된 문제들과 디자인에 대한 개선이 필요하다. 추가적으로 수동 제어의 최적화 및 자율 주행 제어를 목표로 하고 있다. 또한, 실제 서비스와 연계된 구체적인 사용자 컨텍스트를 개발하여 연구에 접목하면 기본 연구의 한계점을 보완할 것으로 기대한다.

핵심어: PMVs, Personal Mobility Vehicles, Autonomous car, Indoor mobility

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DECS 식구들, 우리는 함께 멀리 가는 친구들. 동훈, 병헌, 수교, 성범, Nivi, 윤정, 지환 에게도 고마움을 전합니다. 어떤 일이든 요청하면 뭐든 불도저 식으로 해결해 주는 동훈이, 나의 부족한 디자인적 감각을 함께 고민하고 채워주려고 노력한 수교, 성범, 컴퓨터 공학적인 지식으로 무장하여 나를 서포터 해준 병헌, 초기 연구실 셋팅을 하며 많은 잡무를 함께 해결해 나간 지환, Passionate Nivi, 늦었지만, 합류해서 나에게 홍루이젠을 제공한 윤정, 여러분 덕분에 영감을 얻고 연구에 더 몰입할 수 있었습니다. 앞으로 더 늘어갈 우리 식구들! 또 만나면 족구도 하고 노래방에서 교수님의 노라조 열창 또 들어요!

CDE 친구들, 원도, 가을, 소연, 영철, 용준, 가이, 은준, 경진, 지현, 자영, 경룡, 해빈, 소미, 진희, 초은 ,하연 ,혜민, 교휘, 지수, 동훈, 재한, 상수, 우인, 상진, 무릴로. 어쩜 모두들 이렇게 천차만별 다른 색을 가지고 있는지… 한가지 공통점은 뭔가를 만들고 좋아하는 것. 그런 사람들에 둘러 쌓여 보낸 2 년이 자극도 많이 되고 발전하는 계기가 되었네요. 자영이와 함께 했던 첫 IDP1 프로젝트, 함께 헤매면서 옆 친구들의 우수한 작품을 보며 우리도 꼭 잘해보자고 다짐 했던 기억부터 (결국은 잘 안되긴 했지만;;) 시바우라 공대의 추억, 심천-홍콩 디자인 행군, KIDP 국제 디자인 융합 캠프, 글래스고우 CHI2019 그리고 마지막 수업 디자인 혁신까지 주마등 처럼 흘러가는데 역시 친구들을 만나고 나누었던 좋은 대화들 만이 기억에 남아 있습니다. 사람을 이해하는 것이 디자인의 출발 지점이 아닌가 싶기도 합니다. 모두들 건강하고 졸업이 남으신 분들은 아무쪼록 잘 마무리 하시길! 우리 또 만나요!

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Hug2Go

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